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JAPAN

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Research, Development of SST/HST Called Essential National Project

43062581 Tokyo AEROSPACE in Japanese May 88 pp 30-31

[Report by the Japan Aerospace Industry Association]

[Excerpts] The Japan Aerospace Industry Association completed its interim report on research of planes for the next age sponsored by the Ministry of International Trade and Industry. The report was issued 24 March 1988. This report was summarized by the "Research Committee on Development Trends of Next Age Planes" established under the Japan Aerospace Industry Association. Considering the advanced research and development of the SST/HST in Europe and America, it was determined that Japan should tackle its own research and development as a national project, in order to establish its leading edge in international joint development.

Concerning the future of the SST/HST, this is the first time in Japan that estimates of this nature were prepared from the view of both technology and marketing. The report consisted of two sections: development trends regarding the SST/HST and development trends regarding space vehicles. The following gives a summary of the report on development trends of the SST/HST. Research covered four items: (1) world research trends (2) marketing research (3) technology research (4) tasks for the future. Research on technological progress after the Concord and on the latest world trends was done, and taking these surveys into account, marketing and technology research was carried out.

Results of the Marketing Research

The number of air passengers throughout the world is increasing at an average rate of about 5 percent annually and by the year 2010 the number is expected to be 3.4 times that of 1985. The increase for Asia and the Pacific Ocean region is notably high and the share will expand from the present 16 percent to 31 percent; thus it will become the second largest market following North America.

Considering the operations of the SST/HST for just long distance international lines, the number of routes from Asia and the Pacific region to North America and Europe is increasing 7 to 10 percent. Therefore this is expected to become the main route for the SST/HST in the future.

At present, the main route of the SST/HST between major cities is bounded by three distant points: Asia and the Pacific region, North America and Europe.

As can be seen from the precedent of the establishment of the Tokaido Shinkansen Line, passenger demands for super high speed travel may well increase.

For instance, the required time for 10 hours from Tokyo to Los Angeles at present, will be decreased to 4 hours at Mach 2.5 and to only 2.5 hours at Mach 5. Accordingly, although a departure time from Tokyo was only available in the afternoon (arriving in Los Angeles during the daytime of the same day), flying on the SST/HST will enable one to depart Tokyo in the morning and arrive in Los Angeles during the evening of the preceding day. Thus service will be greatly improved.

The demand for 300-seat-capacity SST/HSTs by the early part of the 21th century is expected to reach between 500 and 1,000 planes. Considering the fact that more than 800 Boeing 747s were ordered over a period of 18 years, this number of planes is justified.

Results of the Technology Research

For the development of the SST/HST, it is extremely important to plan countermeasures against super high speed, high-power cruising and aerodynamic heating.

(1) Promotion

To make the SST/HST a success, an important promotion task is to develop technology which will provide low fuel consumption at subsonic and supersonic speeds which will make crossing the Pacific Ocean possible, a cooling system against aerodynamic heating to cope with the demand of prolonged, super high speed cruising and a low noise level at takeoff to cope with noise pollution at airports.

(2) Structural Material

The structure of the SST/HST will constantly be exposed to high temperature due to aerodynamic heating and extreme low temperature of the fuel tank over long periods. Therefore, the key to building the airframe lies in developing a material which can withstand high and low temperatures as well as in developing a light, heat resistant and adiabatic structure.

(3) Aerodynamics

To build the SST/HST from the aspect of aerodynamics, it is important to develop an airframe which has a high lift-drag ratio (L/D) for supersonic and hypersonic speed.

Another important task in building the airframe is to lower the sonic boom which is related with high performance and keeping noise pollution at airports to a tolerable level.

(4) Summary

The SST/HST will be a big innovation in conventional air transportation and will influence many other related transportation systems. Therefore, it is necessary to consider the SST/HST as a subsystem within the total air and ground transportation system.

(5) Summary of the Main Tasks

Up to Mach 2.2, conventional technology is mainly used, with the exception of VCE (variable cycle engine). But from Mach 2.2 to over Mach 3 a stable jet fuel which can withstand superheat is needed. Furthermore, a light heat resistant material such as titan alloy, FRP and FRM, is required.

At over Mach 4, the surface temperature of the airframe reaches over 500°C, and thus new-concept engines like the turbolum and the ATR are needed. Liquefied methane and liquefied hydrogen are necessary for fuel. For the airframe, superheat-resistant compounds such as carbon carbon and ceramic compounds are necessary. For the structure, thermal protection system (TPS) and active cooling system are necessary. Therefore, large scale research and development for the airframe and the engine is necessary.

Tasks for the Future

(1) Tasks for Next Year

In next year's marketing research, from the flight duration performance possibility (including subsonic speed performance in case supersonic speed at ground level is not possible) which is judged by the airframe specification review program established at the technology level, it is necessary to pursue more accurate basic airframe specifications. At the same time, from the fuel consumption, it is necessary to examine the price of the airframe and other costs to attain a standard fare.

On the other hand, research will have to be done next year on the enhanced consumer demand associated with the introduction of the SST/HST and the appropriate size of the airframe by calculating the number of trips and costs. We must also study the optimum flight schedule that shows the advantages of supersonic speed and gives consideration to passenger convenience and the prohibition of takeoff and landing at night due to noise pollution.

(2) Medium and Long Term Tasks

The necessity for the SST/HST is due to increased long distance air transportation accompanied by the expansion of the Pacific Ocean economic bloc over the 21st century. In America and Europe, research and development have

already been started and promising prospects, though still at an early stage, were proved by a practical market review. Therefore the technical tasks were briefly adjusted.

Based on the results of this research and also on the status of the future market and improved basic technology, it is extremely important that we join the international joint development of the SST/HST which will be proposed in due time. To contribute internationally to the technology tasks which must urgently be researched and developed, it is extremely important to promote the research and development sometime early next year with the cooperation of the government as a concrete R&D project.

It is vital that the project be undertaken as a national project as in America and Europe, for the risks in the technology and marketing fields are too high to be handled by a private organization.

20160/08309

Biomaterials From Natural Polymers

43066086 Tokyo SYMPOSIUM ON PROTEIN-HYBRID in Japanese May 88 pp 31-34

[Article by Yoshito Ikada, Biopolymer Research Center, Kyoto University: "Applications of Naturally-Occurring Polymers as Medical Biomaterials"]

[Text] **1. Introduction**

Polymeric materials are widely used in direct contact with living tissues. They are so-called medical biomaterials. The most significant difference between these medical materials and industrial materials is that medical materials must not be toxic to the living body. "Not being toxic," in this case, means that these materials cause no such side reactions as fever, hemolysis, strong inflammatory reactions, allergies, or malignant tumors. It does not mean that they cause no thrombus formation or encapsulation by collagen fibers. The latter is called bioadaptability, which current biomaterials lack.

Living tissues, which come in direct contact with medical biomaterials, are, broadly speaking, blood, and hard and soft tissues, each of which requires different characteristics in biomaterials. Also, the contact time varies widely from a short period of several hours to a long, semipermanent period. Furthermore, materials, which are biologically absorbed and decomposed, and materials, which absolutely must not decompose, are both necessary. Conditions required of biomaterials are so divergent that the materials with many desired characteristics are being sought. This is why much is expected of natural polymers as medical biomaterials.

2. Current Status and Problems

2.1. Polysaccharides

2.1.1. Mucopolysaccharides

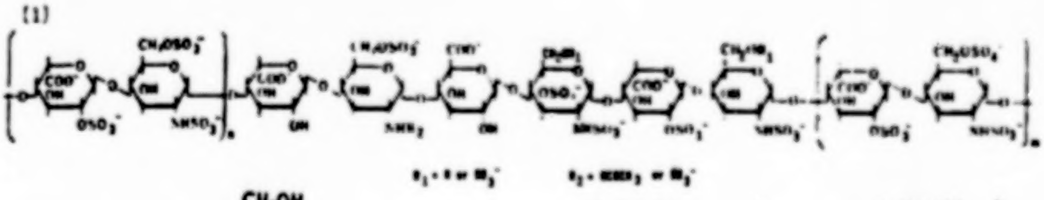
The side chains of proteoglycane is glycosaminoglycane, which is a straight chain anionic polysaccharide and is also a mucopolysaccharide. This substance does not act merely as a structure in the living body but is supposed to be showing certain physiological functions, although the details are not yet clear. The mucopolysaccharide whose physiological

functions are most thoroughly understood is heparin. Its basic structure is posited to be the one shown in [1].

Heparin is by far most important of all natural polymers in connection with medical biomaterial. Heparin possesses anticoagulation (for blood) activity and liposerum clarification activity. The former is used full scale in blood-contacting biomaterials. In other words, in the case of extracorporeal blood circulation with an artificial kidney, an artificial lung, an adsorption-type artificial liver, or a plasma exchange, heparin is always administered to prevent blood coagulation. Without heparin, no artificial organ for blood cleaning would have been used for patients. Although many attempts to synthesize substitutes for heparin have been published, no substitute has yet shown better anticoagulation capability than heparin.

As compared to heparin, hyaluronic acid is much less used, but it is, next to heparin, most closely related to medical biomaterials among the mucopolysaccharides. When the molecular weight of hyaluronic acid is greater than 600,000, its intrinsic velocity becomes greater than 12. A 1 percent aqueous solution of this material is used to protect eye tissues during an operation to insert a lens. It is also used as an artificial vitreous body. In this case, however, according to a published research report, to add the impact absorbability, hyaluronic acid is crosslinked by diepoxide. Hyaluronic acid is also effective for rheumatoid arthritis, and Japan has successfully developed it as a medicine for the first time. Hyaluronic acid is not sulfated as other mucopolysaccharides; as shown in [2], it only has carboxyl radicals. Hyaluronic acid is a unique biodegradable polymer which exhibits high viscosity at low concentrations; and no other biodegradable mucopolysaccharide or synthetic polymer is known to equal hyaluronic acid in that aspect. The use of mucopolysaccharides such as chondroitin sulfate as a medical material is a future research project.

[1]



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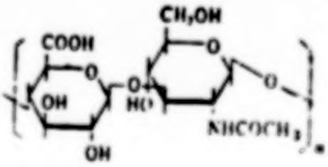

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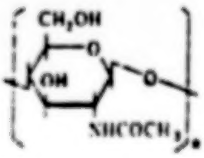

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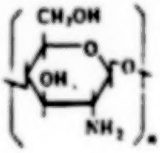

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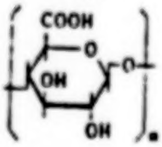


2.1.2. Non-Polysaccharides

The most important structural material for plants is cellulose, as is chitin for crustaceans. Both of these materials are the most abundantly produced natural polymers. Other important natural polymers include alginic acid of the brown algae family, Japanese isinglass of the agar-agar genus, and starch, which is an energy source for plants. However, these medical materials are not as closely related to biomaterials as heparin.

The most important biomaterial among them is cellulose film used for blood dialysis. Cellulose also has a long history. Besides the well known use of gauze as a sanitary material, cellulose oxide, as illustrated in [3], has been clinically used as a bioabsorbable hemostat for at least 40 years. It is not yet clear, however, whether the bioabsorbability of cellulose oxide is due to the biological breakdown of its main chain. No physical change has been noted by merely soaking it in a saline solution. Carboxymethylcellulose (CMC) is on the market under the trade name DESHISAN®, which is imported from East Germany as wound dressing powder. By sprinkling the powder over a wounded area, a film is formed by absorbing moisture. Pharmacia Aktiebolag manufactures a similar powder for wound dressing. This dressing is epichlorohydrin-crosslinked dextran particles.

Pharmacia Aktiebolag is also developing starch microspheres. These are called degradable starch microspheres (DSM) with an almost uniform particle diameter of 40 μm. A certain crosslinking agent can be degraded and absorbed in 2 hours in vivo. Thus, DSM, with an anticancer drug absorbed on it, is used in a short-period drug delivery system (DDS). For the same purpose, chitin's porous microspheres are manufactured in Japan. Chitin, whose structure is illustrated in [4], is a water insoluble polysaccharide and is a bioabsorbable polymer, which can be decomposed by such an enzyme as lysozyme. Industrially chitin is manufactured from the exoskeletons of crustaceans as a raw material. Because of its crystallinity, it can be made into fibers and films; although they are slightly rigid, possibilities for use as an absorbable suture and wound dressing are being studied. Chitosan, as shown in [5], is derived from chitin by hydrolyzing N-acetyl groups and replacing them with free amino groups. Because rather strong inflammatory reactions are observed when the positive charge density becomes high, it is difficult to use chitosan as a bioabsorbable material.

Polysaccharides with dissociable radicals are more interesting as an immunity activating drug than as a medical biomaterial, but we shall not discuss the drug here. Although dextran and hydroxyethyl starch (HES) are clinically used as a plasma extender (frequently used as a biomaterial), it is necessary to watch closely the discharge rate.

Alginic acid and agarose are being used as microencapsulators for Langerhans' islands of an artificial pancreas and, along with agar-agar, as a cell culture matrix.

2.2. Proteins

Collagen, seemingly closely related to biomaterials, is not used at all in large amounts as a general purpose material except as a cosmetic additive and sausage casing. However, in Japan, nonwoven sheets of regenerated collagen fibers are on the market as a biomaterial, but they are not necessarily rated high by medical specialists. Rather, its denatured material, gelatin, has been clinically used far longer than collagen as a drug capsule material, drug coating material, hemostat, and embolism. The reasons collagen's medical applications have not progressed much are its high cost, instability, ready degradability, and low strength. There seems to be a trend, despite its excellent cellular adhesion that cannot be seen in any other polymers, that the characteristics of collagen are not used but collagen is applied in places where strength is required or degradation should not occur. Recently, an artificial skin consisting of silicon and highly water-absorbable collagen sponge has been reported. This is one application of collagen which takes advantage of its unique properties. Results of clinical applications are favorable. In addition, the uses of collagen as a tissue culture substrate, as an injection to restore skin depressions, and for the measurement of platelet coagulability, are considered good examples taking advantage of collagen's properties. Focusing on the cellular adhesivity of collagen, we are conducting research on the immobilization, through chemical bond rather than physical absorption, of collagen on synthetic material surfaces, to which tissue adhesivity is vested. As shown in Figure 1, reasonably satisfactory results have been obtained.

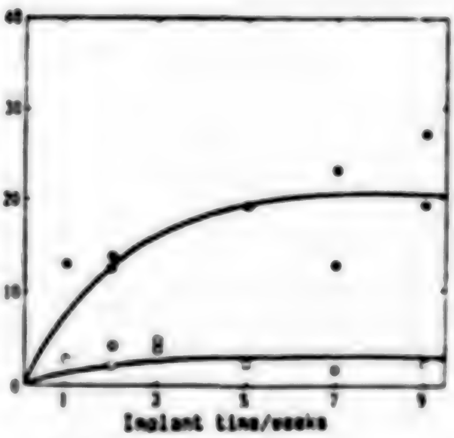
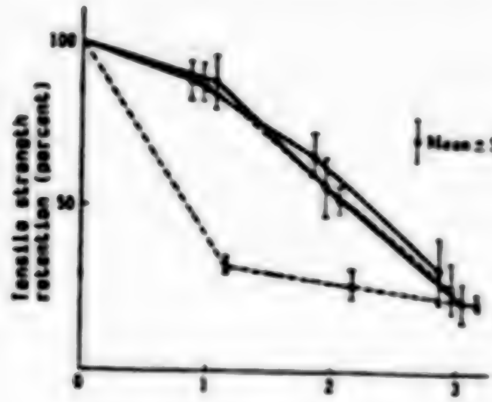


Figure 1. Adhesivity of Silicon With Immobilized Collagen ($1 \times 5 \times 0.05$ m^3) to Biological Tissues After Implant on Muscle Membrane of the Back of Rabbit

Among the applications of natural polymers to biomaterials, we must not forget surgical sutures. Because of low price and ease of use, currently silk sutures are used in the greatest quantities; but, they are nonabsorbable sutures and are losing market share to synthetic sutures of

of polypropylene and nylon. As for absorbable sutures, up until the 1960s, the only absorbable suture was catgut, which is made from animal intestines, but today it is being displaced by polyglycolic acid-type absorbable synthetic sutures. Catgut is cheap, but, as shown in Figure 2, not only is its strength retention poor but it also shows strong biological reactions. Thus, the development of sutures from regenerated collagen has not been successful.



(●) MEDIFIT
(Glycolic acid homopolymer, Japan Medical Supply Co., Ltd.)
(○) DEXON
(Glycolic acid homopolymer, Davis and Geck)
(▲) VICRYL
(Glycolic acid-lactic acid copolymer, Ethicon)
(△) CATGUT

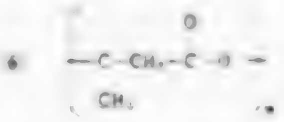
Figure 2. Changes of Tensile Strengths of Absorbable Sutures (USP 3-0) After Subcutaneous Implant in Rabbits

As for the other protein materials, fibrin is used in sheet form as a wound healing aid and in an unpolymerized state of fibrinogen as a biological adhesive. The latter application takes advantage of the reaction of fibrinogen to become three-dimensional in the presence of water and an enzyme. Although its adhesive strength is low, it is used clinically because of its biological absorbability. The thrombolytic catheter with urokinase immobilized on the surface has already been in clinical use, but the uses of human serum albumin and gelatin as a DDS microsphere matrix are still in the research stage. Tubing made by crosslinking human umbilical cord is being used as a replacement blood vessel, sheets made by freeze-drying human hard membrane is used as a surgical reconstruction material. However, these applications do not take advantage of the natural polymers' physiological functions; for the most part, they use the similarities to the dynamic properties of biological tissues.

2.3. Polyesters

It has long been known that certain microorganisms produce polyesters. The best known example is polyhydroxy butylic acid (PHB), shown in [6].

Because PHB can be biotechnologically synthesized, it is also drawing attention in Japan. However, the possibility of application to medical biomaterials appears to be low because of high cost and low biodegradability. If produced at lower cost, it might be used for DDS and in agriculture.



3. Conclusions

As discussed above, polysaccharides, proteins, and polyesters among the natural polymers are either currently used or about to be used as medical biomaterials. Nucleic acids are not yet targets of research.

Some readers must have been surprised by the wear connections between the natural polymers and biomaterials, with the exceptions of the regenerated cellulose dialysis membrane and heparin. It is natural to think the connection is close, because the main components of our living bodies are natural polymers. However, there is no reason that nonartificial materials must have good affinity toward the living body. If a piece of animal muscle is implanted in our muscle, the animal tissue will be rejected extremely violently, but, in the case of a nonbiological material such as silicon, the biological response reaction is incomparably milder.

The characteristic of biodegradable absorbability can be a serious shortcoming if the target for use is not chosen correctly.

Excellent physical properties, not biological properties, are most strongly sought by today's biomaterials. Serious errors are likely if research is carried out aimlessly on the basis of mere biological similarities. Natural polymers are promising biomaterials, as shown in Figure 3, because they possess an extremely elaborate multidimensional structure. Their use where strength is required must be avoided, as these materials cannot be reconstructed.

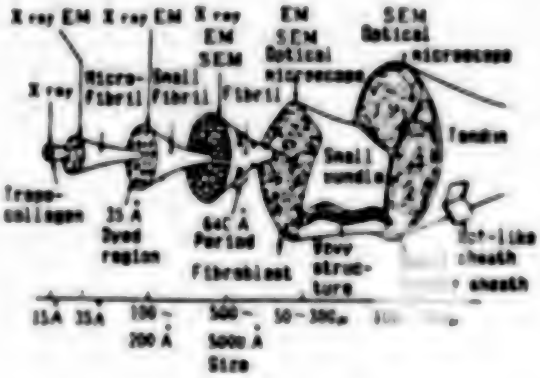


Figure 3. Microstructure of Tendon

13382/9365

Reports on Diagnostic Bioreactors

43066087 Tokyo SYMPOSIUM ON PROTEIN-HYBRID in Japanese May 88 pp 45-58

[Two articles under the special topic of "Diagnostic Bioreactors" written by the research team of Kyoto University]

[Excerpts]

Bioreactor for Diagnostic Use
by Takashi Murachi

The purpose of diagnostic bioreactors R&D is to manufacture bioreactors containing chips with fixed biocatalysts for use in analyzing the composition of blood and/or urine in disease diagnosis. In the first chapter, a bioreactor is described and one of its characteristics, reaction directionality, is discussed with the focus on the comparison between a biosensor and a bioreactor.

Introduction: The treatment and prevention of disease basically presuppose correct diagnosis. Diagnosis is built on the combination of clinical opinions obtained from listening directly to the patient's complaints, and on test results, objective analytical results obtained through examination. The latter analysis corresponds to the medical behavior usually called clinical examination. Among the examinations, the qualitative and quantitative analysis of body fluids (blood and urine, in particular) is most numerous. This is the clinical chemistry (biochemical) analysis which is called "clinical analysis." It has grown so much that it has become an independent science by itself, separate from general chemical analysis; it is also used in a wide range of fields.

In the last 20 years this clinical chemical analysis has seen a significant technological revolution. One change was the adoption of automatic analysis equipment. Another was the introduction of various enzymes as analytical reagents. In clinical analysis, there are severe restrictions on the quality and quantity of obtainable samples. In addition, since so many pieces of component information are needed from a very small amount of a precious sample, the development of reagents, which display a high degree of selectivity (unique property) to each component, was demanded. Many of these reagents turned out to be unique enzymes necessary to satisfy the needs.

When multi-item analyses of a large number of samples are conducted by using automated apparatus and enzymatic reagents, it is natural to devise a method to use natural reagents of an enzyme with a higher added value rather than use a reagent once and throw it away. In fact, already in the chemical industry, enzymes are used as a reaction system which can withstand repeated uses and is easily controlled. With this line of thinking, the concept of the diagnostic bioreactor was initiated.

Development of the Diagnostic Bioreactor

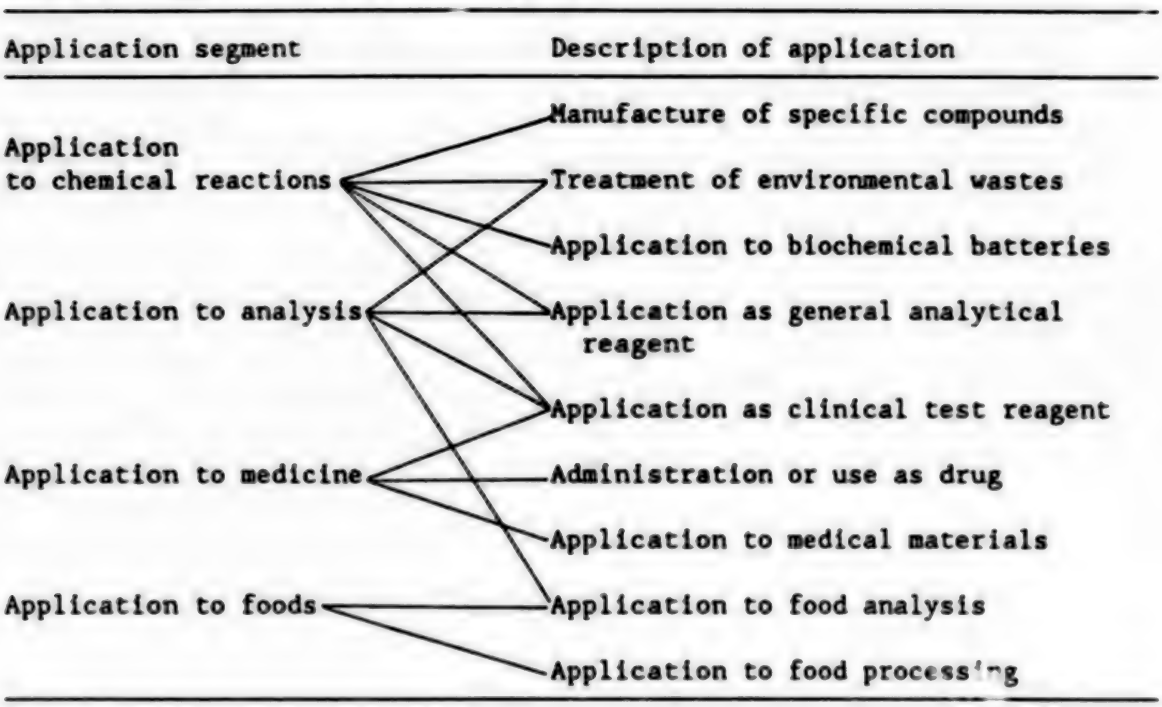
To develop a diagnostic apparatus of the basic structure type (which has reactor chips lined up along the flow of the sample liquid, a sample entering from the upper stream, and signals emerging from the lower stream), the author and his colleagues felt the need for thorough basic research on the various phases which are described below. Fortunately, from 1977 on we were able to advance our research as a part of the Institute of Physical and Chemical Research project called "R&D on Diagnostic Bioreactors," which was carried out as part of national policy.

The "R&D on Diagnostic Bioreactors" project was pursued not only by the laboratory of the author who was in charge of the development of a new type of diagnostic analyzer equipped with a fixed enzyme reactor at its core, but also under a cooperative system of eight university research laboratories mainly in the Kansai District. Pilot operations were included in the project and run under the responsibility of the private sector. Research was conducted on the following topics: 1) development and fabrication of useful enzymes; 2) new development of improvement of enzymatic analytical methods; 3) development of reaction system and instrumentation system; 4) research on sample treatment methods; and 5) design, proto-type, and evaluation of new model equipment.

In this special series of articles, after explanations of the concepts and characteristics of diagnostic bioreactors in the first chapter, the current status of research on the fixed enzyme reactor, the foundation for diagnostic bioreactors, will be discussed. Several examples of the progress in related supporting technologies will be described.

Summary: In Table 2 a wide range of applications of bioreactors are summarized. According to this table, the R&D on diagnostic bioreactors should come under the application in the form of clinical test reagent. As is self-evident from the lines drawn in Table 2, the progress of applications in this segment will widely influence the chemical industry, as well as the medical and food fields. Also, the progress in other fields will certainly influence these segments through feedback. In this sense, the author will continue to hope that this little segment on clinical examinations, a subject usually distantly related to readers of this journal, will be a new stimulus for further dissemination.

Table 2. Applications of Bioreactors



Fixed Enzyme Reactors--Their Use With Chemiluminescence Detection
by Masayoshi Tabata, Masayuki Totani, and Takashi Murachi

The core of a diagnostic bioreactor is a reactor containing biological component-analyzing reagent enzymes fixed in a solid phase. The fixed enzyme reactor must be small in size, unique in reactivity, able to withstand continuous use, and emit appropriate signals as a part of an analytical apparatus. In this article, the basic technology for the manufacture of a fixed enzyme reactor, which can satisfy the above requirements, will be described first. Then, actual examples of clinical chemical analyses using fixed enzyme reactor will be shown. Finally research results will be discussed, specifically the combination of the reactor with a detection system by chemiluminescence to improve analytical sensitivity (hence, to do microanalysis).

Introduction: In human bodies, decomposition and synthetic reactions are carried out to maintain life. Almost all catalysts for these reactions are enzymes, which are functional polymers with a high degree of specificity. It is certainly natural and reasonable to use these enzymes as a useful tool in medical fields which deal with the living body. In fact, in clinical chemical analysis, analytical methods based on chemical reagents were once used, but recently, because enzyme reagents are more suitable for clinical chemical analyses, analytical methods based on enzyme reagents have been used more frequently in place of chemical methods. During the past 20 years or so, the technology to mass produce useful enzymes originating from microbes, and to purify enzymes on a commercial scale has advanced. Today, that technology, coupled with the progress of enzyme

Table 1. Clinical Chemical Analyses With Enzymatic Reagents

Analysis target	Main enzyme reagents	Final signal
Glucose	Glucose oxidase	H_2O_2
	Pyranose oxidase	H_2O_2
	Hexokinase & glucose 6-phosphoric acid dehydrogenase	NAD(P)H
	Glucose dehydrogenase	NAD(P)H
Cholesterol	Cholesterol oxidase	H_2O_2
	Cholesterol dehydrogenase	NADH
Cholesterol esters	Cholesterol esterase & Cholesterol oxidase	H_2O_2
Neutral fat	Lipase & Glycerol dehydrogenase	NADH
	Lipase & Glycerol kinase	ADP
	Lipase, Glycerol kinase, & Glycerol-3-phosphoric acid dehydrogenase	NADH
	Lipase & Glycerol oxidase	H_2O_2
Phospholipids	Phospholipase C & Alkali phosphatase	Pi
	Phospholipase D & Choline oxidase	H_2O_2
Free fatty acids	Acyl CoA synthetase & Myokinase	ADP
	Acyl CoA synthetase & Acyl CoA oxidase	H_2O_2
Urea	Urease	NH_3
	Urease & Glutamic acid dehydrogenase	NAD(P)H decrease
	Urease, Glutamic acid dehydrogenase, & L-Glutamic acid oxidase	H_2O_2
Ammonia	Glutamic acid dehydrogenase	NAD(P)H decrease
	Glutamic acid dehydrogenase & L-Glutamic acid oxidase	H_2O_2
Uric acid	Uricase	H_2O_2
Creatinine	Creatinase, Creatinase & Sarcosine	H_2O_2
	Oxidase (Sarcosine dehydrogenase)	(NADH)
	Creatinine deaminase	NH_3
Bilirubin	Bilirubin oxidase	O_2 decrease
Bile	3α-Hydroxysteroid dehydrogenase	NADH
Lactic acid	Lactic acid dehydrogenase	NADH
	Lactic acid oxidase	H_2O_2
Pyruvic acid	Lactic acid dehydrogenase	NADH decrease
	Pyruvic acid oxidase	H_2O_2
Sialic acids	Neuraminidase, NANA-aldolase & Pyruvic acid oxidase	H_2O_2
Amino acids	L-Amino acid oxidase	H_2O_2
Magnesium	Hexokinase & Glucose 6-phosphoric acid dehydrogenase	NADPH
Inorganic phosphorus	Pyruvic acid oxidase	H_2O_2
	Purine nucleoside phosphorylase & Xanthine oxidase	H_2O_2
Cholinesterase activity	Choline oxidase	H_2O_2
Amylase activity	α-Glycosidase & Glucose oxidase	H_2O_2
AST activity	Glutamic acid dehydrogenase	NADH
	Malic acid dehydrogenase	NADH decrease
	Oxaloacetic acid dehydrogenase & Pyruvic acid oxidase	H_2O_2
ALT Activity	Lactic acid dehydrogenase	NADH decrease
	Pyruvic acid oxidase	H_2O_2
	L-Glutamic acid oxidase	H_2O_2

chemistry has shown developments in the applications of enzymes to clinical analyses which are essentially different from a long time ago.

The dream of using enzymes repeatedly instead of disposing of them after a one-time-use, has been almost realized by the emergence of fixed enzymes. In other words, by the introduction of the enzyme fixing technology, enzymes, or catalysts, are stabilized, and are used repeatedly with recycling after each use. Furthermore, they can be packed at a higher density in a given space. Thus, fixed enzymes are playing an important role as a functional chip for bioreactors.

Today, we have so many enzymatic analytical methods in daily use that the era has arrived when almost all nonproteinaceous organic components, some inorganic components, and enzymic activities of enzymes, such as amylase, as well as of serum, can be analyzed by method using enzymes as reagents (Table 1). Some of these reagent enzymes, in the form of fixed enzymes, have been tried in applications to clinical chemical analyses. Fixed enzyme reactors have already been commercialized in the following examples: glucose oxidase or hexokinase and glucose 6-phosphoric acid dehydrogenase for glucose determination, urease for urea determination, and uricase for uric acid determination. Recently, making use of the photographic films manufacturing technology, the dry reagent chemistry method has been developed to enclose enzymes inside a multilayered film. Eastman Kodak and Fuji Photo Film Co., Ltd., are marketing the products, which have become popular in clinical chemical analysis. This enzyme embedded multilayer film is one type of application of fixed enzymes.

The already commercialized enzyme immunoassay, a powerful analytical method for determining a microquantity component of a biological sample, uses fixed enzymes; however, its discussion is omitted here, because the method differs some from the definition of reactors. Furthermore, the applications of fixed enzyme reactors to the medical treatment areas, such as enzymatic treatment, medical polymeric materials, and artificial organs, will not be presented here so as to limit our discussions to the applications to the diagnostic areas (clinical chemical analysis).

Fixation of Enzyme

To maintain an enzyme's functions as much as possible when it is bound to or enclosed by a polymeric carrier, it is absolutely necessary to fix the enzyme protein without losing its stereostructure and to position its active sites in a manner which is most advantageous to the display of its functions. For that reason, many carriers and fixing methods have been developed or improved.

1. Enzyme Fixing Methods

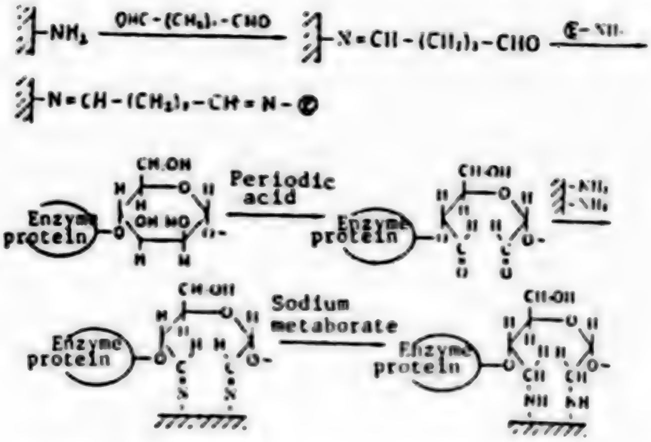
There have been many reports on enzyme fixing methods which are roughly divided into the carrier bonding method, the crosslinking method, and inclusion method. The carrier bonding method bonds an enzyme with a water insoluble carrier. Depending on the mode of bonding, this method can take

Table 2. Examples of Enzyme Fixation by Covalent Bonding Method

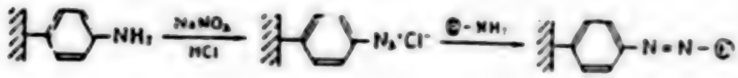
(1) Schiff's reagent bonding method

(a)

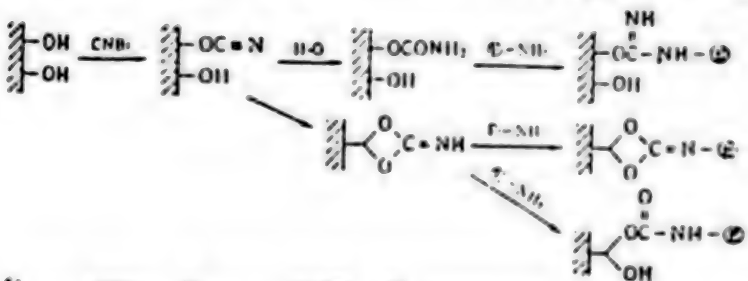
(b)



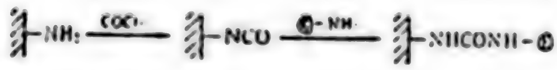
(2) Diazonium coupling method



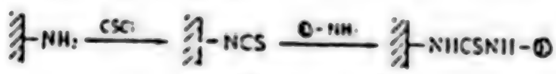
(3) Cyanogen bromide activation bonding method



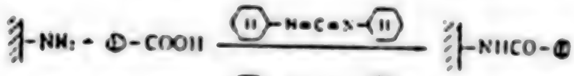
(4) Bonding method to isocyanate derivatives



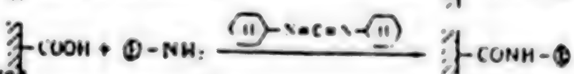
(5) Bonding method to isothiocyanate derivatives



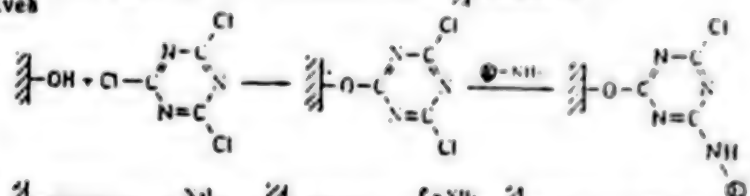
(6) Bonding method through condensation reagent



(7) Bonding method to triazinyl derivatives

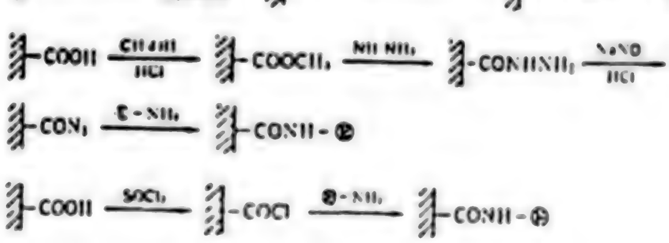


(8) Bonding method to halogenoacetyl derivatives



(9) Bonding method to oxyazide derivatives

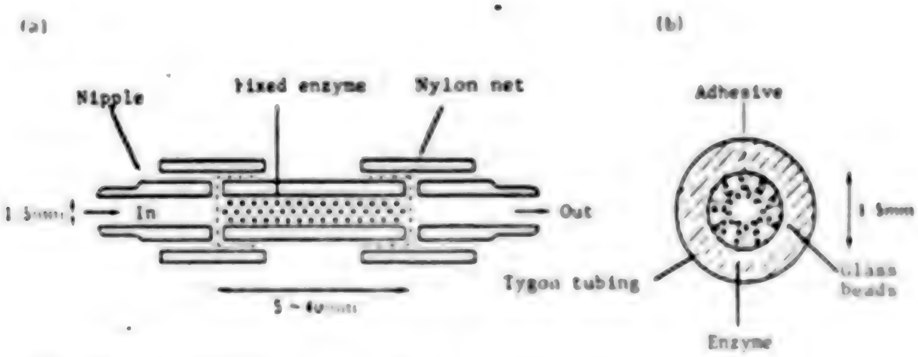
(10) Bonding method to carboxychloride derivatives



many different forms. For example, the absorption method is a method to have an enzyme adsorbed on or hydrophobicly bonded to a carrier such as an ion exchange resin. the covalent bonding method is a method to bind an enzyme through the covalent bond to the preactivated surface of a polysaccharide derivative, such as agarose, or porous glass beads. The ionic bonding method is a method to bind an enzyme through the ionic bond to a carrier with ion exchange groups. The crosslinking method does not use a water insoluble carrier; instead, it immobilizes enzymes by interenzymatically crosslinking with a reagent having two or more functional groups. The inclusion method is divided into the lattice type and the microcapsule type. An example of the former is the fixing of an enzyme by enclosing it in an acrylamide network when the enzyme is mixed with the polymer's gel. The gel is then packed in a column 1.5 mm in diameter and 20 mm in length; the column is connected to a continuous flow system. When a deaerated flow is poured directly into the column at a rate of 1 ml/min to check for pressure loss, there is no appreciable loss of pressure and no effect on analytical results.

2. Enzyme Tubing

The enzyme tubing comes in two types: one is a tubing with an enzyme immobilized on its inner wall by some method, and the other is a tubing with porous glass beads adhering to its inside and an enzyme fixed on the glass beads (Figure 1(b)). In the latter scheme, porous glass beads coat on the tubing's inside wall to increase the surface area, hence to increase the amount of fixed enzyme. Therefore, it has become possible to reduce to a length to 10 cm or so the previous tubings of several meters in length. In comparison to the column reactor, the tube reactor's activity was less influenced by the flow rate through the reactor.



(a) Mini-column with packing of enzyme-fixed glass beads
(b) Enzyme tube with enzyme fixed on glass beads adhering on its inner wall

Figure 1. Example of Fixed Enzyme Reactor

3. Enzyme Membrane

There are two forms of enzyme membranes: one is the membrane (enzyme membrane), which is formed after an enzyme has already been included in or bonded with a polymer, and the other is the membrane (enzyme-bound membrane), which is preformed and to which an enzyme is bonded later.

Table 3. Fixation of Several Enzymes

Enzyme	(mg)	Carrier[a]	(mg)	Fixation method[b]	Yield (%)	Relative activity (%)
Uricase	5	AA glass	200	GA	68	53
	9.5	Nylon 12 tube	3 m	GA	26	
Glucose oxidase	8	Cepharose	350	CNBr	80	55
	10	AA glass	200	GA	50	37
	10	AA glass	200	Saccharide residues	85	58
	40	AA glass	500	Diazo method	65	
Cholesterol oxidase	1	AA glass	100	GA	95	
Cholesterol ester hydrase	3	AA glass	200	GA	90	
Cholesterol oxidase Cholesterol ester hydrase	1.5 3	AA glass	200	GA	85	
Glucose oxidase Peroxidase	10 5	AA glass	300	Saccharide residues	70	60
Peroxidase	15	AA glass	300	GA	40	
	15	AA glass	200	Saccharide residues	85	74
Urease	9	AA glass	200	GA	61	70
Pyruvic acid oxidase	10	AA glass	200	GA	90	
Glutamic acid dehydrogenase	10	AA glass	200	GA	72	
Creatinine deaminase	10	AA glass	200	GA	56	
Creatininase	10	AA glass	200	GA	92	
Hexokinase	10	AA glass	200	GA	80	
Glucose-6-phosphoric acid dehydrogenase	10	AA glass	200	GA	80	
L-Glutamic acid oxidase	10	AA glass	200	GA	92	

a) AA Glass: Alkylamine glass beads
b) GA: Glutaraldehyde method, Saccharide residues: Fixation method using saccharide residues

Today, these membranes are used as the enzyme membrane for enzyme electrodes.

Application of Fixed Enzyme as Analytical Reactor

To incorporate a fixed enzyme, as a functional chip, into a continuous flow-type autoanalyzer, such as those represented by autoanalyzers and FIA systems, it is most appropriate to adopt those fixed enzyme columns in which the dispersion of solutes in the counterflow direction is minimum. Discussed below are examples of the analysis which has become possible by

the use of a fixed enzyme reactor with directionality for the passages of liquids.

1. Application to Autoanalyzer

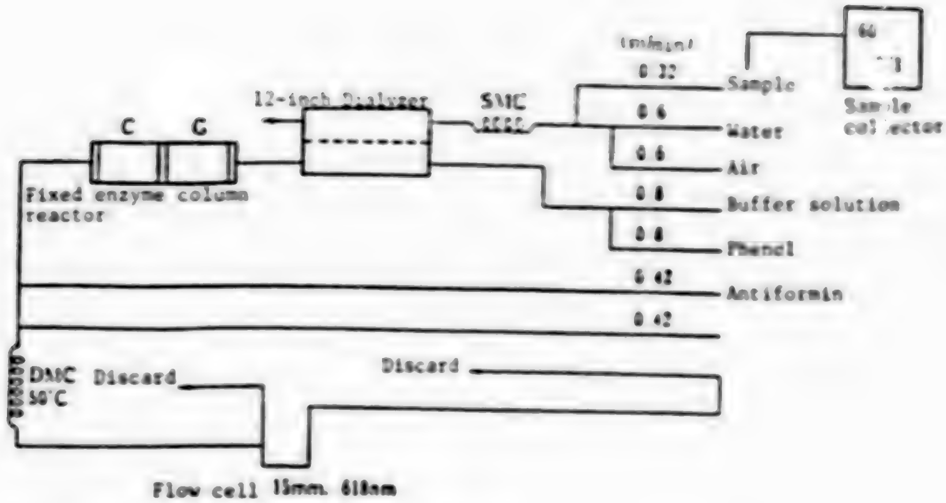
In Figures 2 and 3, summaries are illustrated for the system to determine creatinine in serum by incorporating a dual fixed enzyme column into the autoanalyzer of Technicon, Inc. First, glutamic acid dehydrogenase (GLDH, Proteus sp., Toyogo Co., Ltd.) and creatinine deaminase (Corynebacterium lilium ATCC, 15990, Kyowa Hakko Kogyo Co., Ltd.) were fixed separately on porous alkylamine glass beads. The two kinds of beads in equal portion were then alternately packed in layers in a minicolumn (1.5 mm in inner diameter and 60 mm in length) before incorporation into the autoanalyzer. The principles of the measurement are as follows. First, free NH_3, which originally exists in serum, is removed from the solution by the fixed GLDH reactor (Equation (1)). Next, creatinine solution with the NH_3 removed passes the creatinine deaminase reactor, whereby creatinine is hydrolyzed to form NH_3 (Equation (2)). Finally, the newly formed NH_3 is analyzed by the indophenol reaction (Equation (3)) to determine creatinine. Since the concentration of original NH_3 in serum is almost equal to the concentration of NH_3 formed by the hydrolysis of creatinine at a normal concentration, the free NH_3 in serum cannot be ignored and must somehow be removed from the solution. The method described here has become a simple measuremen system, which does not require blank channels, because it has become possible to separately advance the GLDH reaction (Equation (1)) and the creatinine deaminase reaction (Equation (2)) by using the directional fixed enzyme reactor.

$$NH_3 + \alpha\text{-ketoglutaric acid} + NADPH + H^+ \xrightarrow{GLDH} \text{L-glutamic acid} + NADP^+ \tag{1}$$

$$\text{Creatinine} + H_2O \xrightarrow{\text{Creatinine deaminase}} \text{N-methylhydantoin} + NH_3 \tag{2}$$

$$NH_3 + \text{phenol} \xrightarrow{\text{Sodium nitroprusside}} \text{indophenol blue} \tag{3}$$

The two enzymatic reactions of GLDH and creatinine deaminase have different optimal pH values. When these two reactions are carried out continuously in the same buffer solution, the pH of the buffer solution significantly influences the rates of reaction. Figure 4 shows the pH-activity curves for GLDH and creatinine deaminase. When GLDH and creatinine are used in combination, the optimal pHs for soluble enzymes are 8.0 to 8.5, while the same for fixed enzymes are 7.5 to 8.0, i.e., the latter range shows a large expansion toward the acid side. Particularly, it is more noticeable with fixed GLDH and its apparent K_m value decreases significantly (Table 4). Because of that, the difference between optimal pHs of the two enzymes becomes smaller.



C: Fixed creatinine deaminase column reactor
G: Fixed glutamic acid dehydrogenase column reactor
SMC & DMC: Single & double mixing coils, respectively

Figure 2. Flow Diagram for Analysis of Serum Creatinine by Autoanalyzer Equipped With Fixed Creatinine Deaminase and Glutamic Acid Dehydrogenase Column Reactor

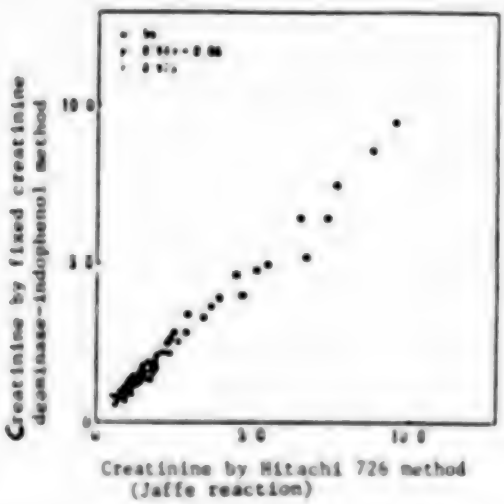


Figure 3. Correlation of Hitachi 726 Method and Fixed Creatinine Deaminase-Indophenol Method for Creatinine

Thus, in the present method, the two enzymatic reactions were carried out in a buffer solution of pH 7.5. With this method, it was possible to analyze 60 samples in an hour; linearity was obtained to the creatinine concentration of 10 mg/dl; reproducibility was good; no influence of creatine was found; free NH_3 of up to 3 mg/dl concentration could be completely removed. Results of the serum creatinine measurement by the present method were slightly lower than those obtained from the Hitachi 726

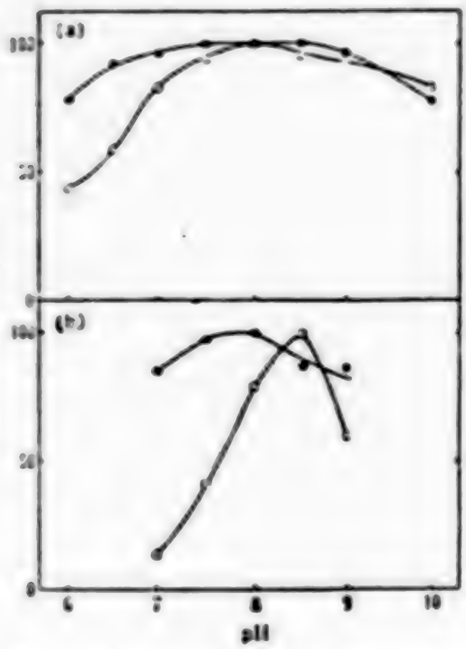


Figure 4. Activity Vs. pH Curves of (a) Creatinine Deaminase, and
(b) Glutamic Acid Dehydrogenase (GLDH)
(●) Fixed enzyme
(o) Soluble enzyme

autoanalyzer using the Jaffe reaction ($y = 0.94x + 0.06$), but they showed good correlation ($\gamma = 0.0975$) (Figure 3).

2. Application to FIA System Combined With Chemiluminescence

Among the analytical methods using luminescent phenomena in solutions are the bioluminescence method and the chemiluminescence method. Some bioluminescence methods are being used for specific analyses, e.g., firefly luciferase for ATP determinations, bacteria luciferase for NADH determinations, and peroxidase and luminol for H_2O_2 determinations. Recently, both of the luminescence analytical methods have been applied to enzymatic immunoassays and biological component analyses. In this paper, however, the authors discuss the chemiluminescence method using $K_3Fe(CN)_6$ and luminol to analyze living components.

As shown in Table 1, the three main final signals of enzymatic reactions are H_2O_2, NH_3, and NAD(P)H. However, the luminol chemiluminescence method can actually determine only H_2O_2 and cannot measure the others. When the enzymatic reactor developed by the authors is used, NH_3 and NAD(P)H can be transformed into H_2O_2; thus, it has become possible to determine NH_3 and NAD(P)H by the luminol chemiluminescence method. The measurement principles involved are that NH_3 react with α-ketoglutaric acid by the GLDH reaction to become L-glutamic acid, which, in turn, is oxidized by L-glutamic acid oxidase (GLXD, Streptomyces, sp., Yamasa Shoyu Co., Ltd.) to form H_2O_2. In other words, by the two enzymatic reactions of GLDH and GLXD, one mole of NH_3 is transformed into one mole of H_2O_2 by the following equations:

Table 4. Apparent K_m Values of Glutamic Acid Dehydrogenase (GLDH) Against Ammonia and of Creatinine Deaminase Against Creatinine

		K_m		
Enzyme	pH	Soluble (mM)	Fixed (mM)	Ratio (Sol/fixed)
GLDH	7.5	3.3	0.08	41
	8.5	1.1	0.08	14
Creatinine deaminase	7.5	1.3	1.9	0.69

$$NH_3 + \alpha\text{-ketoglutaric acid} + NADPH + H^+ \xrightarrow{GLDH} \text{L-glutamic acid} + NADP$$

$$\text{L-glutamic acid} + O_2 \xrightarrow{GLXD} \alpha\text{-ketoglutaric acid} + NH_3 + H_2O_2$$

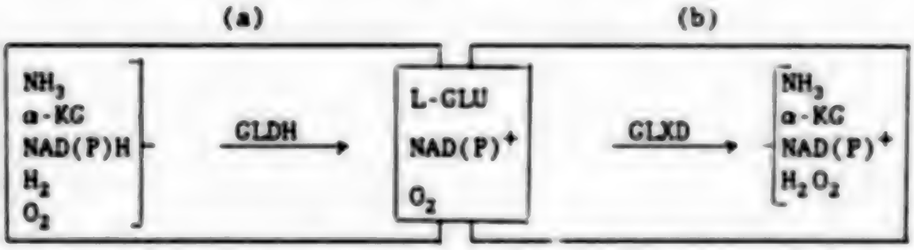


Figure 5. Fixed GLDH-GLXD Column Reactor for Ammonia Determination
(a) Fixed Glutamic acid dehydrogenase (GLDH) reactor
(b) Fixed L-Glutamic acid oxidase (GLXD) reactor

By measuring this H_2O_2 by the luminol chemiluminescence method, the concentration of NH_3 can be obtained. Analyses using this principle cannot be carried out with soluble enzymes which lack directionality. In other words, when L-glutamic acid is oxidized by the GLXD reaction, H_2O_2 as well as NH_3 is produced, and since this NH_3 becomes the substrate for the GLDH reaction, the original NH_3 cannot be determined if a soluble enzyme is used. However, by using the fixed enzyme column reactor developed by the authors, shown in Figure 5, it is possible to measure NH_3 by the chemiluminescence method. Fixed GLDH and fixed GLXD are packed in tandem in the column, and an NH_3 solution is passed under pressure by a pump. Because NH_3 formed by the GLXD reaction is forced out of the column, it does not come in contact with the fixed GLDH; thus, it is possible to measure only NH_3, which has, from the first, existed in the solution. Next, by using the column reactor (Figure 6), in which layers of fixed urease, GLDH, and GLXD are packed in that order, it is possible to

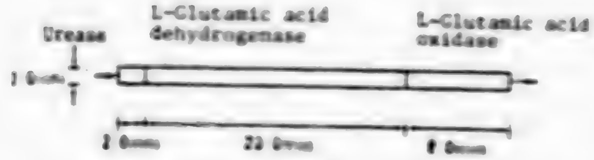


Figure 6. Fixed Enzyme Reactor for Urea Nitrogen Measurement Used in Conjunction With the Flow Injection Analytical Method

determine urea nitrogen by analyzing NH_3, which is formed when urea is hydrolyzed by urease, as shown below.

$$(NH_2)_2CO + H_2O \xrightarrow{\text{urease}} 2NH_3 + CO_2$$

For the measurement of urea nitrogen, fixed urease, GLDH, and GLXD are packed with the layers of 2 mm, 20 mm, and 8 mm thickness, respectively, in the column 1 mm in inside diameter and 30 mm in length.

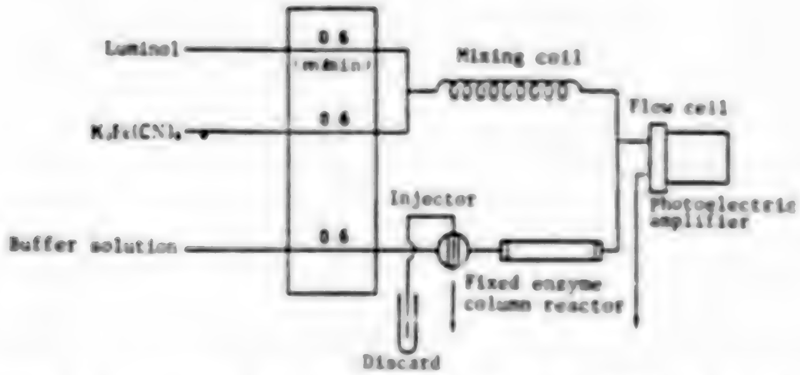


Figure 7. Diagram for Flow Injection Analytical Method

Figure 7 shows the flow diagram for the urea nitrogen determination by the FIA system. Reagents used were a pH 7.5, 10 mM phosphoric buffer solution containing NADPH and α-ketoglutaric acid, 0.7 mM luminol, and 20 mM $K_3Fe(CN)_6$. The resulting pH value of a mixed solution of the three reagents at the exit of the reaction cell significantly influenced luminescence intensity, and the optimal pH was about 10.5. Solutions of luminol and $K_3Fe(CN)_6$ also effect greatly luminescence intensity. By merely mixing two solutions of luminol and $K_3Fe(CN)_6$, a reasonable amount of luminescence is noted. Therefore, if a H_2O_2-containing buffer solution and a luminescent reagent are allowed to react directly with each other, it becomes impossible to determine the intensity because a very high background value obscures the real value. Thus, it is necessary, in advance, to cause the solutions of luminol and $K_3Fe(CN)_6$ to react together in the premixing coil. The mixture, after its luminescence has died down, is made to react with the H_2O_2-containing buffer solution to cause chemiluminescence by the target material to occur. For the photometer, a device was made by gluing a spiral reaction cell to the light receptor of a photoelectric amplifier (Figure 8). Since the photometer needed neither a light source nor a prism, both of which a spectrophotometer needs, and because it needed only a device to detect the quantity of photons, the

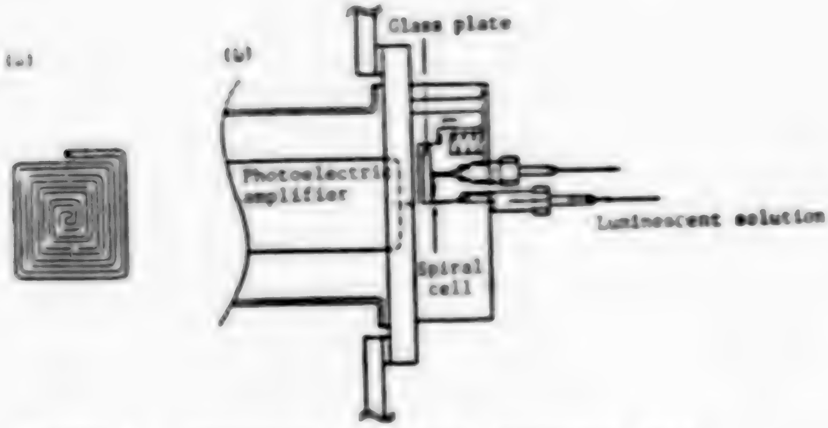


Figure 8. Structure of Spiral Reaction Cell
(a) Front view of spiral reaction cell
(Size: 0.7 x 0.7 x 196 mm,
Capacity: 96 μl)
(b) Side view of photometer equipped with
spiral reaction cell

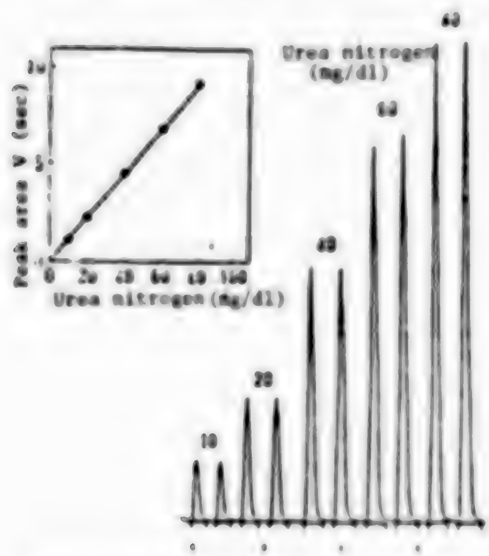


Figure 9. Analytical Curves and Determination Standard
Line for Standard Urea Nitrogen Solutions

device itself was simpler and smaller than a spectrophotometer. The flow passage is made of Tygon tubing of 0.5 mm in inside diameter, and the flow rate of each reagent was 0.6 ml/min. When 1 μl of blood serum from an injector is injected into the buffer solution tube, the data will emerge approximately 10 seconds later. Unlike the air separation method, the FIA method uses a small diameter tubing and a short flow passage to allow enzymatic reactions to proceed efficiently by limiting as much as possible the spread of a sample injected into the buffer solution tube. As a result, fast and high precision determinations become possible. The

accuracy and the precision of the 1 μl injector are 1.024±0.005 μl (average ± 2 SD) and CV = 0.223 percent, respectively. The recorded analytical curves and the determination standard line for urea nitrogen by the present method are illustrated in Figure 9. A straight line was obtained up to a urea nitrogen concentration of 80 mg/dl. Also, satisfactory correlation (γ = 0.997, y = 1.06x + 0.36) was gained between these results and those by soluble urease-indophenol colorimetry (Figure 10).

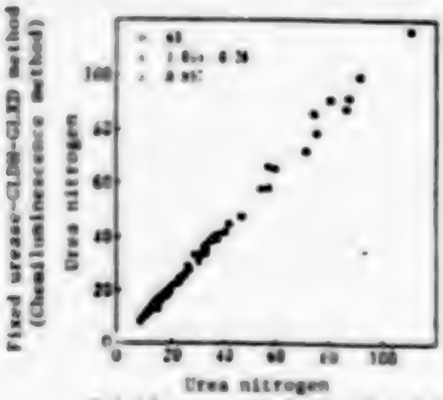


Figure 10. Correlation Between Soluble Urease-Indophenol Colorimetry and Fixed Urease-GLDH-GLXD Chemiluminescence Method

Stability of Fixed Enzyme Reactor

The stability of a fixed uricase (Candida sp., Toyobo Co., Ltd.) reactor as compared to the stability of soluble uricase is illustrated in Figure 11.

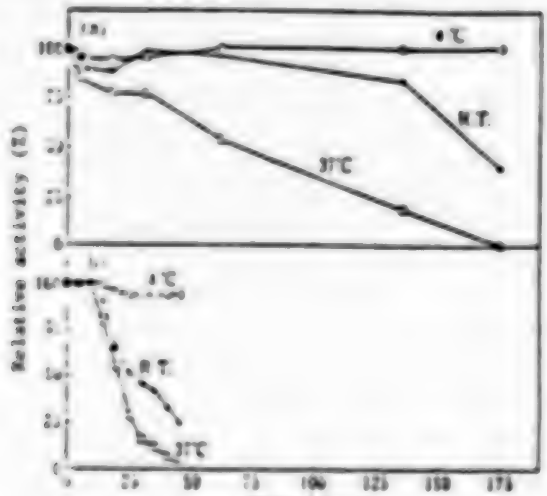


Figure 11. Stability of Fixed Uricase Reactor (a) and Stability of Soluble Uricase (b)
R.T.: Room temperature

Each of these reactors, during a period of 175 days, was used eight times for a total of 1,100 cases of sample analysis at about 25°C; when not in use, they were stored in a pH 7.0 phosphate buffer solution, which were

held at 4°C room temperature, and 37°C. The reactor is 1.0 mm in inside diameter and 20 mm long. Soluble uricase solubilized in a pH 7.0 phosphate buffer solution was also stored at 4°C, room temperature, and 37°C, and enzymatic activities were measured at 25°C. The uricase reactor, even 175 days after its use, if kept at 4°C, can maintain the same level of enzymatic activity as at the time of reactor manufacture. If kept at room temperature, 130 days after its use the reactor kept about 40 percent of the original activity. Although enzymes are said to be generally stabilized by fixing, it is clear from the results shown that the fixed uricase reactor is far more stable than soluble uricase.

Summary: The fundamentals of the technology to apply a column reactor containing fixed enzyme(s) to clinical chemical analyses and a few of its practical examples have been discussed. In addition to the advantage that enzyme reagents can be used repeatedly, we have learned that the technology is useful in the following ways.

(1) By using a fixed enzyme reactor, the difference between the optimal pHs of two enzymes was decreased and measurements could be done in a neutral pH region. Furthermore, two successive enzymatic reactions were run efficiently; i.e., we were able to build an efficient reactor (Figure 4).

(2) Because the fixed enzyme reactor has directionality, it could be used as a precolumn (Figure 2). In addition, the reactor operated extremely effectively in a system in which concurrent multiple enzymatic reactions were not wanted (Figures 5 and 6).

(3) In cases where two enzymes were fixed, the method of fixing the enzymes simultaneously to one carrier was found simpler in adjustment operations and more sensitive as a bioreactor than the method of fixing each reagent separately to separate carriers and mixing them in certain proportion in a column.

(4) We were able to unify the final signals by running a variety of apparently different enzymatic reactions, through the reactor with directionality.

Using a combination of these advantages, we believe that the time is near when a practical diagnostic bioreactor will appear on the market.

13382/9365

Summary of TRDI's Technical Reports

Missile Guidance System

43062570 Tokyo BOEI GIJUTSU in Japanese Apr 88 pp 32-33

[Article by Hirofumi Eguchi, Kazumitsu Obana, Kenji Watanabe, and Toshiyuki Tanaka, technical officials of the Third Laboratory, Third Division, Guidance First Laboratory: "Study of Design Methods for Missile Guidance Control Systems"]

[Excerpt] 1. **Purpose**

In recent years, active efforts have been made to develop missiles--particularly air-to-air missiles--capable of high elevation angle flight, especially with a high BTT (bank-to-turn) ratio, in order to improve missile maneuverability. These missiles require designs for a multi-input multi-output (MIMO) guidance system instead of past designs based on classical control theories. Our research focused on combining the system analysis method by singular values proposed by Doyle, et al., in 1981 with the LQ theory in a simple example as one possible design method for a MIMO control system.

2. Methods and Contents of Testing

Figure 1 shows the system composition. Design procedures are summarized as follows:

(1) Determine the desired performance data (bandwidth, unexpected random frequencies, expected noise frequencies, margin of stability, sensitivity characteristics, etc.) and plot singular values that regulate them on a board figure.

(2) Determine the optimum gain by LQ/LQG methods.

(3) Compose the feedback compensator so that the board plot of singular values regulating respective performance becomes as close as possible to the board plot in (1) and the feedback gain becomes as close as possible to the optimum gain obtained near the crossover frequency (2).

(4) Confirm asymptotic stability of the feedback loop by inverse Nyquist array (INA), characteristic loci (CL), etc.

(5) Improve quick responsiveness to commands through the precompensator.

(6) Confirm that the required gain margin is maintained by the gain margin-phase margin (GM-PM) diagram of the entire system.

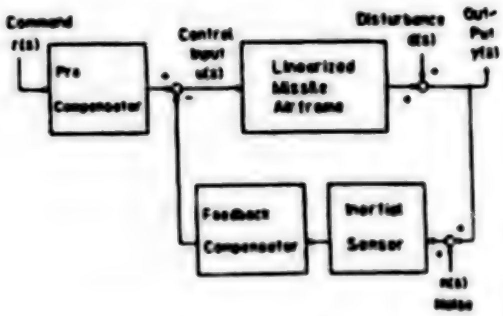


Figure 1. Control System for Missile Autopilot

3. Results

We designed a sample missile autopilot system having proper performance characteristics. Figure 2 shows a representative plot of two singular values regulating performance. Subscript "O" indicates target values and "D" represents design results.

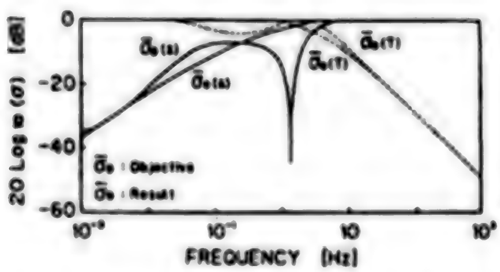


Figure 2. Example of Singular Value Plot

4. Consideration

In this research, the factors that regulate the performance of the control system were clearly linked with the limits and singular values for the system. It was shown that an effective method is required for designing the MIMO system in the frequency space. However, little consideration was given to the phase information at this point, and we view this as a subject to be studied in the future.

TEA CO_2 Laser Device

43062570 Tokyo BOEI GIJUTSU in Japanese Apr 88 pp 33-34

[Article by Toshiya Mizuta, technical official of the Third Laboratory, Third Division, Guidance Second Laboratory, and Satoru Kobayashi, technical official of the Second Laboratory, Third Division: "Test Results of TEA CO_2 Laser Range-Finding Device"]

[Text] 1. **Purpose**

In order to put optical tracking devices using the one-point observation method to practical use, we have manufactured a range-finding device that can be mounted on an existing cinesextant using a TEA CO_2 laser that poses no danger to the eyes of the operators. Field tests using helicopters confirmed its measuring accuracy and its maximum range. Good results were obtained, and these are described below.

2. Methods and Contents of Testing

The TEA CO_2 laser used in the test is a Model-220 produced by the TACHIST Company of the United States. It has a 6.6 MW (max) output, a 60 nsec pulse duration, and 20 pps maximum repetition. The range-finding device shown in Figure 1 was manufactured using this TEA CO_2 laser, and an optical tracking device for one-point observation was composed by mounting it on a cinesextant stand.

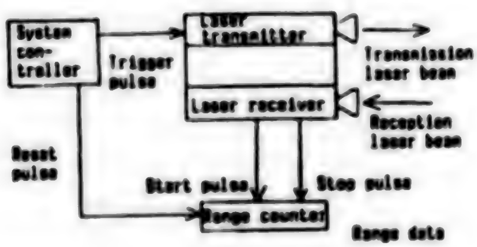


Figure 1. System Diagram of TEA CO_2 Laser Range Finder

This optical tracking device was tested in the field. Its range-finding accuracy was confirmed by conducting tests where 4 m poles to which arrayed corner reflectors were fixed were set in a straight line at a distance of 738 m - 798 m with a space of 10 m between fixed targets.

The maximum range-finding scope of the device was confirmed by conducting range-finding tests for moving targets using a helicopter to which a corner reflector 3 inches in diameter was fixed.

3. Results and Consideration

The results were evaluated using an average distance $\overline{R}$, a range-finding error of $\Delta R = \overline{R} - Ro$, and a standard deviation σ obtained from about 200 measurements. It was determined that both R and o are less than 1 m

(Table 1). The results of the range-finding tests using a helicopter showed the device to be accurate within the circle (R_{max} = 10 km) in which the helicopter could be tracked.

Table 1. Test Results of Range Finding Accuracy

Ro(m)	$\bar{R}$(m)	ΔR(m)	σ(m)3
738	737.8	-0.2	0.94
748	747.4	-0.6	1.08
758	757.9	-0.1	0.99
768	767.9	-0.4	0.93
778	777.9	-0.1	0.90
788	787.7	-0.3	1.0
798	798.0	0	0.98

Based on the above results, we conclude that a range-finding device using a TEA CO_2 laser can be effectively put to practical use as a range-finding device for an optical tracking device.

Target Simulation Device

43062570 Tokyo BOEI GIJUTSU in Japanese Apr 88 pp 34-35

[Article by Shigeru Dozono and Isao Tokaji, technical officials of the Third Laboratory, Third Division, Guidance Third Laboratory: "Infrared Image Model for Sliding Door Type Simulation"]

[Text] 1. **Preface**

With the improvement of infrared CCD technology and digital picture processing technology, the pace of R&D on missiles with infrared image guidance systems is about to quicken. Therefore, the establishment of an evaluation system for missiles using this technology has become an urgent necessity. In physical simulation tests, however, improvement of responsiveness and enhanced resolution are technical problems that need to be overcome to achieve a faithful modeling of infrared targets. No models have yet appeared that can adequately satisfy this requirement. We have test manufactured a sliding door type infrared image generation device (Slidir) and evaluated its performance. The results of this evaluation are reported in this article.

2. Methods and Contents of Testing

Figure 1 [not reproduced] shows the external appearance, structures, and measurements of the Slidir and its mount, which were test manufactured in July 1987. Simulated target images with a space resolution vertically divided into two and horizontally into four are realized by a fixed rectangular radial blackbody and a sliding door structure with three boards (one blackbody board and two background boards) on the left and right sides and one each (background board) on the top and bottom. The temperature of

each element can be controlled independently with a range of temperature difference from -10 to about 40°C between the element and the background with a resolution of 0.1°C. The approaching distances of targets are expressed with high responsiveness by moving the sliding doors with a servo mechanism and by similarly magnifying and reducing the measurements of the aperture. Temperature around the aperture is not controlled, which simulates the target background.

As for performance evaluation, space resolution, temperature resolution, transient response, stability, etc., against the moving speed of various temperature patterns and the sliding door were measured by making the Slidir face the infrared camera (an AGEMA Thermovision 782).

3. Results and Consideration

An effective temperature resolution of 0.1°C satisfies the requirement. There are no problems with transient response in practical use because temperature changes from -10 to 40°C occur within 1 minute. A little temperature rise of the background board was observed during continuous operations of more than 1 hour, but this creates no major problems with stability for practical use. For space resolution, dividing it into eight is the limit of the present design technology, and modelization fidelity is also limited. However, since this device is designed for use in evaluation tests of future antiship missile guidance devices--such as bomb guidance device SGCS-1 and ASMs--it is believed that it will be adequate as a model simulating a ship on the sea. It is possible to achieve high resolution by increasing the number of sliding doors.

Defense Signature System

43062570 Tokyo BOEI GIJUTSU in Japanese Apr 88 p 35-36

[Article by Isao Tokaji, technical official of the Third Laboratory, Third Division, Guidance Third Laboratory, and Masasato Kadoshika, technical office of the Second Laboratory, Second Division, Radiowave Third Laboratory: "Image Flowing of Military Image Systems and Visual Characteristics."

[Text] **1. Purpose**

In a high information society supported by integrated circuit technology, digital signal processing technology, etc., a great deal of this information is conveyed in image form. The effectiveness of imaged information has been noted and R&D in this area is actively advancing. Picture processing means forming pictures that can be easily judged by man as the final output, except to obtain numerical results by processing the picture signals. Therefore, it is important to understand the visual characteristics of humans when developing new picture systems or creating optimum designs. Military image systems require special consideration in the area of man-machine interface. For example, one question is how a man can detect and identify targets from moving pictures generated by camera systems mounted on the mobile platforms of missiles, aircraft, motor

vehicles, etc., as represented by new multiple MAT or LANTERN (low altitude infrared night navigation sighting) devices. We have measured the influence of the image flowing of a television monitor on the visible probability of targets, or visual characteristics of image flowing. This article reports the results of our study.

2. Methods and Contents of Testing

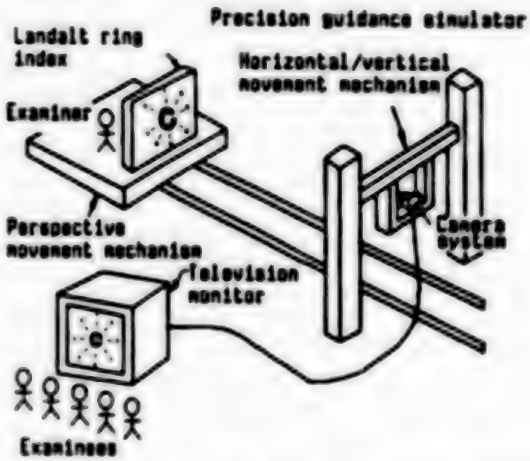


Figure. Arrangement of Measuring Devices

The arrangement of the measuring devices is shown in the figure. In order to quantitatively measure the ability of visual systems to identify fine things, or space resolution, the Landalt ring used for eyesight tests was used as an index. Not only silicon vidicon cameras but also silicon CCD cameras were used as camera systems to confirm the influence of solid cameras. To simulate mobile platforms, a precision guidance simulator possessed by the Third Laboratory was used. The Landalt ring index was set on a perspective movement mechanism and a camera system was set on the horizontal and vertical movement mechanism. In this time measurement, visibility tests were conducted for horizontal and vertical motions. The examiner in the figure tested four to five examinees by turning the index at random and had the examinees tell the direction of the opening of the ring, which is divided into eight directions, from the moving pictures on the screen of the television monitor. This test was repeated 20 times for the moving speeds of the respective cameras, and statistics on visibility characteristics were measured.

3. Results and Consideration

Absolute visual characteristics depend not only on picture flowing speed, but also on such parameters as the visual process of the examinees, lighting, camera resolution, and the size and resolution of the displays. All test results were evaluated by normalizing the characteristics of still pictures to see only the effects of picture flows on the sense of sight. As a result, the effects of picture flows on the reduction of detection/identification probability was quantitatively measured. We hope this will serve as basic data for the system design of new image systems.

Wide-Range Antenna

43062570 Tokyo BOEI GIJUTSU in Japanese Apr 88 pp 36-37

[Article by Osami Yoshizawa, Isao Hara, Shigeo Kawasaki, Takeo Yamaoka, and Yoshitaka Nakasato, technical officials of the Third laboratory, Third Division, Guidance Seventh Laboratory: "Characteristics of Wide-Range Antenna in Low Band Regions"]

[Text] 1. **Purpose**

Aircraft onboard antennas for radar warning devices and antiradar missile guidance devices require a wide receiving bandwidth but must be small in size and light in weight. One antenna that satisfies this requirement and that can be used to conduct angle measurement with a single antenna is the four-arm spiral antenna. Although it is known that the receiving bandwidth of the antenna is determined by the outer diameter of the antenna and the size of the feeder at the center, there is still some question about its practical receiving bandwidth. In order to obtain basic data on the outer diameter and the lowest limit for the practical receiving frequency of this antenna, we test manufactured a four-arm spiral antenna and measured its characteristics in low bands. This article reports the results of those tests.

2. Methods and Contents of Testing

The primary performance characteristics of the test-manufactured antenna are shown in the following table.

Table. Antenna Performance Characteristics

Item	Performance date
Frequency range	UHF band - C band
VSWR	Less than 2.3
Gain	More than 0 dBlc
Outer diameter	330 mm

(1) Voltage standing wave ratio (VSWR) characteristics

Reflection loss of each output terminal of the antenna was measured using a network analyzer, and its VSWR was obtained.

(2) Gains, receiving patterns, phase characteristics

A mode forming circuit was added to the antenna, and its gains, receiving patterns (total and differential) and phase characteristics were measured.

3. Results and Consideration

Part of the measurement results is shown in the figure. From these results, it was confirmed that the antenna could be put to practical use even in frequencies lower than the lowest limit $\lambda \leq \pi D/2$ (λ: wavelength; D: antenna diameter) of the receiving frequency that was explained on the current mode. Basic data on extending the use of the antenna to low band regions were also obtained.

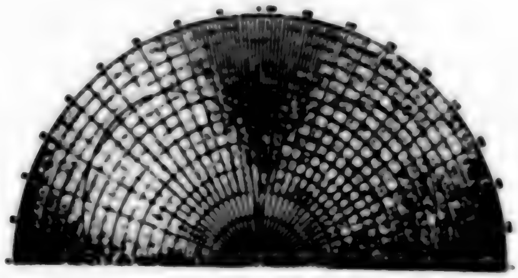


Figure. Difference Pattern (UHF band)

20155/9365

Summaries of Defense Academy's Technical Reports

Infrared Light Detection Element

43062571 Tokyo BOEI GIJUTSU in Japanese Apr 88 pp 38-40

[Article by Takumi Fujimoto, student of electronics and transmission engineering: "Warm Carrier Infrared Light Detection Film Element"]

[Excerpt] 1. **Foreword**

Superhigh-speed response warm carrier elements that function at room temperature were designed as detection elements that can act across a broad spectrum from microwaves to the infrared regions. We have been researching ways to make them into a thin film. We learned that we could produce an element with a detection sensitivity against a CO_2 laser beam.[1] However, its detection sensitivity was 2-3 figures lower than that of a point contact type. Also, it was necessary to subject it to intensified processing at a temperature of 400°-450°C in order to improve its detection sensitivity. In actual high temperature intensified processing, the film would become detached from the Ge and SiO_2 electrodes which created a problem. This research also revealed a problem with electrode exfoliation. Consequently, we examined a number of electrode missiles to find those that could stand the heat treatment necessary for the elements.

2. **Effects of Heat Treatment on Electrodes**

Figure 1 shows the structure of the manufactured element. The element consists of a planar electrode directly contacting a P-type Ge whose resistivity is about 10 Ωcm together with a 4 μm-wide and 950 μm-long film antenna on the SiO_2. There is an ultramicro hole about 0.1 μm in diameter formed by the irradiation of a focused ion beam at the tip of the antenna, and the antenna electrode makes a point contact with the Ge through this ultramicro hole.

In the element shown in Figure 1, wire breaking of the film electrode during heat treatment occurs mainly at the point contact portion of the tip of the antenna electrode. The greater part of this electrode is on the SiO_2. The electrode to be used in this element is required 1) to come into ohmic contact with the Ge; 2) to have a strong mechanical adhesion to the SiO_2; 3) not to become detached from the SiO_2 during heat treatment;

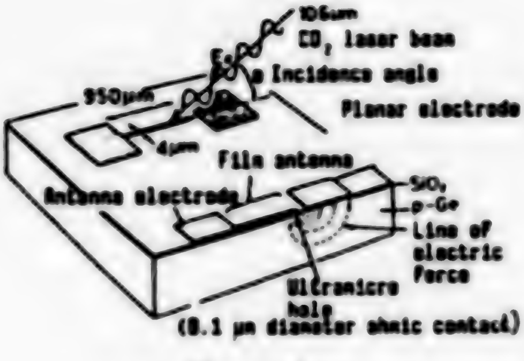


Figure 1

4) to have a low contact resistance (electrode resistance) with the Ge; and 5) not to react to the Ge (resistance of the electrode itself is not changed by heat treatment). For our research, we chose Au, AuPd, Al, AlAu, Ni, Cr, NiAu, AuNiAu, and CrAu as elements for electrodes that would satisfy the first condition noted above. These electrodes were manufactured on the SiO_2 by spattering or vacuum evaporation. We then conducted tests to see how they met the second and third requirements.

In the experiment, an ultrasonic washer was used to produce mechanical vibration. The elements underwent successive heat treatments in an N_2 atmosphere up to 450°C, at intervals of 25°C. Figure 2 shows the test results. The vertical lines represent mechanical strength while the horizontal lines depict heat resistance. (In fact, the vertical axis represents the output of the ultrasonic washer and the horizontal axis is the heat treatment temperature.) The points where the spattered or vacuum-evaporated electrodes on the SiO_2 showed changes were plotted. Figure 2 shows that Cr, Ni, and AuPd provide good heat resistance and mechanical strength. Au does not have good mechanical strength but does offer good heat resistance.

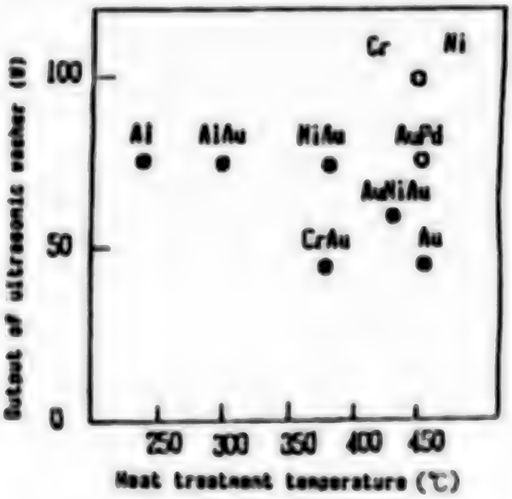


Figure 2

From this experiment, we concluded that Cr, Ni, and AuPd are good for electrodes on the SiO_2. We conducted experiments to find suitable electrodes for the Ge by adding Au to these elements. Figure 3 shows the relation between contact resistivity and heat treatment obtained from the experiment conducted on the Ni electrode for the Ge. Contact resistivity was obtained by extrapolation.[2] It increases some after the first heat treatment (300°C), but it does not show big changes after that. No great differences in contact resistivity were observed among different electrode materials.

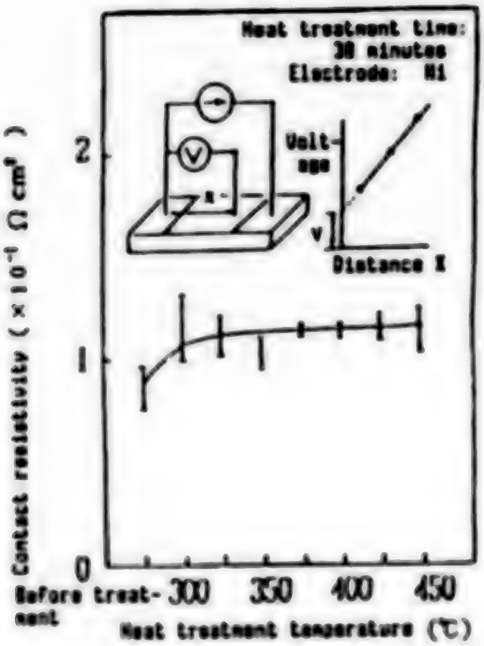


Figure 3

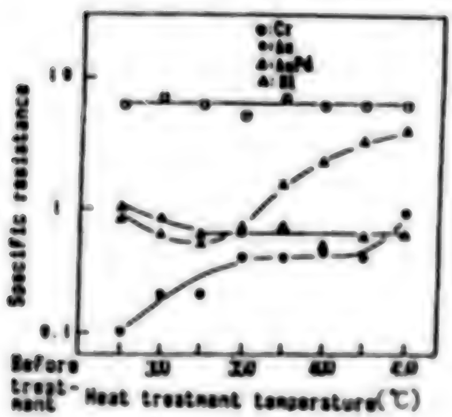


Figure 4

Figure 4 shows the relation between specific resistance and heat treatment temperature before heat treatment when the resistivity of Ni is set at 1. The specific resistance of Ni and Cr show little change when the heat

value. By contrast, the resistance of Au tends to increase along with the rise in the heat treatment temperature. The resistance of AuPd increases after 350°C. Surface observation with a microscope revealed a ball-up phenomenon[3] on the surface of the Au and the AuPd during a 350°C heat treatment.

Table 1 summarizes the results of this experiment. It can be seen that Ni displays both good resistivity and mechanical strength as an electrode on both SiO_2 and Ge.

Table 1

		On SiO_2		On Ge			
		Adhesion	Surface	I-V characteristics	Contact resistivity	Specific resistance	Surface
Au	Vacuum evaporation	Δ	o	o	o	Δ	Δ
AuPd	Vacuum evaporation	o	o	o	o	X	Δ
Cr	Vacuum evaporation	◎	o	o	o	Δ	o
Ni	Evaporation	◎	o	o	o	o	o

3. CO_2 Laser Beam Detection Sensitivity-Heat Treatment Dependency

We investigated the detection sensitivity-heat treatment dependency of a warm carrier film element of an Ni electrode against a CO_2 laser beam with an output of about 2 W. Heat treatment was conducted in an N_2 atmosphere using a gold furnace. First, a heat treatment at 450°C for 30 seconds was conducted seven times. Subsequently, heat treatments of 10 and 20 minutes were conducted in an electric furnace. Figure 5 shows the detection voltage, thermal component, and heat treatment dependency of the resistance. As heat treatment time increased, resistance and thermal component decrease--become saturated. But it can be seen that the detection voltage reaches its peak after 2 minutes of heat treatment (four times for 30 seconds) and the detection voltage becomes about six times greater than it was before the heat treatment.

These results suggest that the disturbance in crystallization is recovered by the heat treatment, and detection sensitivity is enhanced.

This experiment produced no evidence of a disconnection of the electrode from the Ge or of unstable element characteristics. This suggests that it may be possible to intensively process the manufactured warm carrier film element when Ni is used as an electrode.

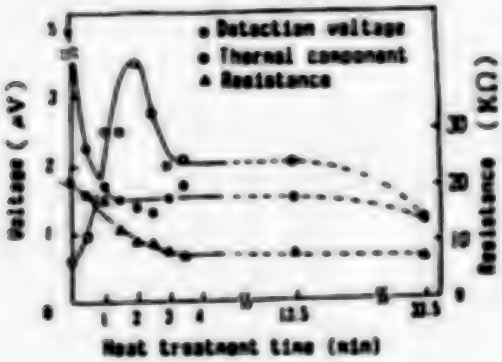


Figure 5

4. Conclusion

Our research showed that an Ni electrode provides good heat resistance and mechanical strength when used as the electrode in a warm carrier film element. Heat treatment at 450°C becomes possible through the use of Ni, and a detection sensitivity about six times greater than that before heat treatment can be obtained by four heat treatments at 450°C for 30 seconds each.

In the future, further improvement of sensitivity can be expected by the study of heat treatment.

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Guiding Instructor: Professor Yoshizumi Yasuoka

Microwave Nonreciprocal Phase Shifter

43062571 Tokyo BOEI GIJUTSU in Japanese Apr 88 pp 40-43

[Article by Shingo Honda, student of electronics and transmission engineering: "Design of CW Microwave High-Power Nonreciprocal Phase Shifter"]

[Text] 1. **Foreword**

There is considerable interest in creating effective high-power nonreciprocal phase shifters in order to develop high-power isolators, circulators, etc., which in turn are important for the industrial application of high-power microwaves. Since ferrite is often damaged by heat generation in such high-power phase shifters, it is necessary to examine the thermal distortion inside the ferrite. Nonreciprocal phase

shifters have to date been designed by the perturbation of the electromagnetic field from basic waveguide mode, or TE_{10} mode. However, it is understood that the dielectric constant or ferrite actually has a great influence on the electromagnetic field distribution in the ferrite and the inside waveguides. This article will describe a new design method for high-power CW nonreciprocal phase shifters that takes into consideration the electromagnetic field distribution, and stress distribution of ferrite to improve both the phase shifters and the test results.

2. Design Method

(1) Electromagnetic Field

Ferrite is considered to be a dielectric substance, and the electromagnetic field distribution of the phase shifter in Figure 1 was analyzed using "the popularized transmission equation."[1] Electromagnetic field distribution, which is the sum of the mode function in an empty waveguide, was obtained by a HITAC M-200H computer using 45 modes of TM and 44 modes of TE.

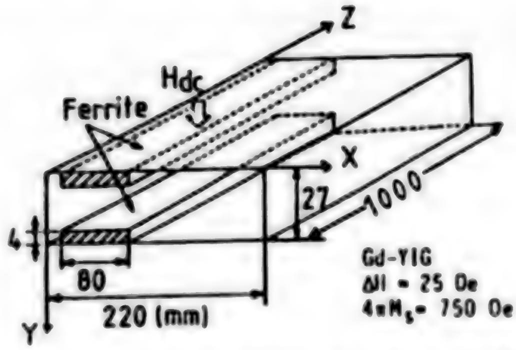

Figure 1. Nonreciprocal Phase Shifter

(2) Nonreciprocal Phase Calculation

Effects of tensor μ of the ferrite on which a direct current magnetic field is impressed and the propagation constant taking into consideration ϵ'' of ferrite can be expressed in the following formula, which derives from a perturbation calculation.[2]

$$\Gamma_+ + \Gamma_0^* = \frac{j\omega\int_{\Delta S}(\Delta\epsilon E\cdot E_0^* + \Delta\overleftrightarrow{\mu}H\cdot H_0^*)\,ds}{\int_s i_z(ExH_0^* + E_0 xH)\,ds}$$

Where: $\Delta\overleftrightarrow{\mu} = \overleftrightarrow{\mu} - 1$

$\Delta\epsilon = -j\epsilon''$

ω: Angle frequency

E: Electric field in phase shifter

H: Magnetic field in phase shifter

E_0^*: Complex conjugate of electric field E_0 before receiving perturbation

H_0^*: Complex conjugate of magnetic field H_0 before receiving perturbation

i_z: Unit vector in the direction of Z

In making the calculation, it was supposed that $E \approx E_0$ and $H \approx H_0$ in the above formula.

(3) Temperature Distribution in Ferrite

Generated heat can be calculated from the μ'' and ϵ'' values of the electric field and the ferrite. Temperature distribution was obtained by the following heat conduction equation using differential calculus. The size of the mesh was 0.5 mm.

$$\rho C \cdot \frac{\partial T}{\partial t} = q + r\nabla^2 T$$

Where:
- ρ: Density (g/m^3)
- C: Specific heat (cal/g°C)
- q: Generated heat (cal)
- T: Temperature (°C)
- t: Time (s)
- r: Heat conductivity (cal/s·m°C)

Next, an experiment using a 2.45 GHz CW 5 kw nonreciprocal phase shifter was conducted, and the experimental values and calculated values were compared and examined. Noncontact temperature measurements of the ferrite surface were conducted using infrared thermometers by a method shown in Figure 2. Figure 3 shows the experimental values and the calculated values. This confirmed the appropriateness of the calculation methods for electromagnetic field and temperature distribution, because, as this figure shows, there is a close correlation between the experimental values and the calculated values.

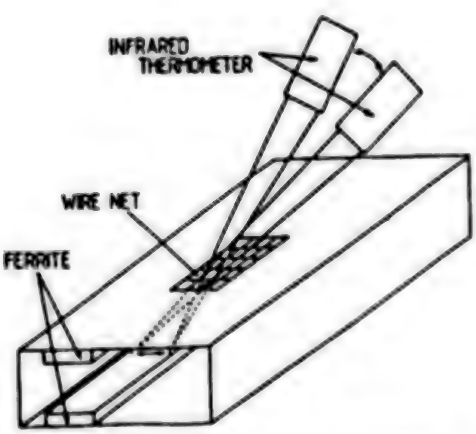

Figure 2. Noncontact Temperature Measurement Using Infrared Thermometer

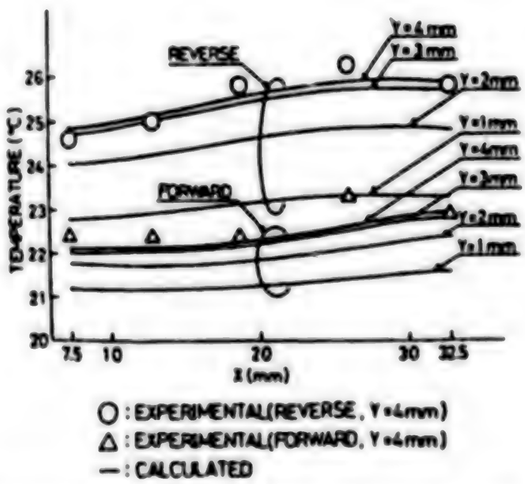

Figure 3. Temperature Distribution (Calculated values and experimental values)

(4) Thermal Stress distribution in Ferrite

Thermal stress distribution was obtained using the following formula based on the temperature distribution observed during the experiment:

$$\sigma_{ik} = 2G[\epsilon_{ik} + \frac{\nu}{1-2\nu} \left(e - \frac{1+\nu}{\nu} \alpha\tau\right)\delta_{ik}]$$

Where: $e = \epsilon_{xx} + \epsilon_{yy}$
$2G = E/(1 + \nu)$
E: Young's modulus (kg/m^2)
ν: Poisson's ratio
ϵ: Distortion
σ: Stress (kg/m^2)
α: Linear expansion coefficient
τ: Temperature change
δ: Delta of Kronecker
$i,k = x,y$

3. Application to High-Power Nonreciprocal Phase Shifters and Conclusion

Based on these results, two CW 250 kw nonreciprocal phase shifters were combined to produce the CW 500 kw circulator shown in Figure 4. The nonreciprocal phase shifter consists of a multilayer structure, as shown in Figure 5, which was designed as a nonreciprocal phase shifter at 915 MHz for input up to 500 kw. Figure 6 shows the results of the calculation of temperature distribution when CW 500 kw is inputted into the phase shifter. The results, shown in Figure 6, indicate the upper limit of temperature rise calculated in conditions where the total reflection, or thermal stress to the ferrite, is supposed to be the maximum. Thermal stress distribution can be obtained using this result. Figure 7 shows the results obtained. The oblique lines in Figure 7 show the limit of stress with which the ferrite is broken. These were obtained by bending tests. From this it can be seen that the ferrite in the phase shifter is not broken because the maximum value of the main stress in the ferrite is lower than the critical stress value (point at which the ferrite is broken).

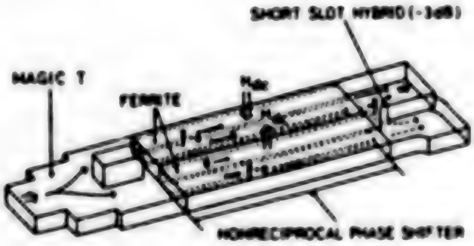

Figure 4. Circulator

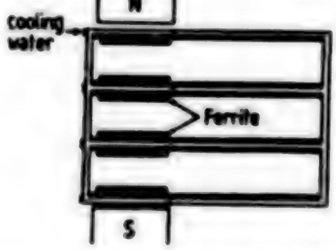

Figure 5. Multilayer Nonreciprocal Ferrite Phase Shifter

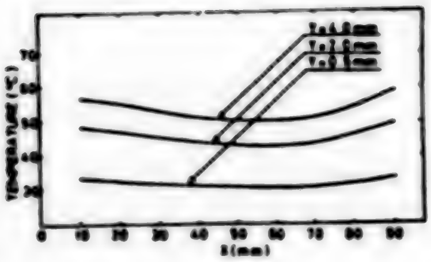

Figure 6. Temperature Distribution in Ferrite (Calculated values)

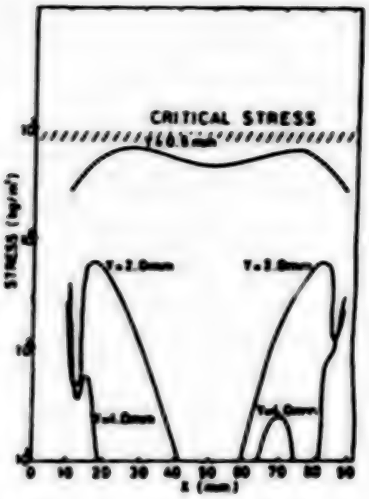

Figure 7. Calculation Results of Main Stress

The experiments also showed that this phase shifter could be operated with high power up to 915 MHz 500 kw.[3] The design method described above can be easily applied to the development of high-power nonreciprocal phase shifters for other frequencies and electrical powers.

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Guiding Instructor: Professor Fumiaki Okada

Light Position Detection Element

43062571 Tokyo BOEI GIJUTSU in Japanese Apr 88 pp 43-45

[Article by Tadashi Gyoji, student of electronics and electronic circuits: "Research on Light Position Detection Elements Using Photoconductive Effects of Pb_2CrO_5 Film"]

[Text] 1. **Foreword**

Developments in electronics have led to the emergence of a high information society. Information input means represent an important factor for output

display devices. Among them, many optical sensors are utilized in our daily life,[1] and high-performance optical sensors are desired.[2]

Recently, our group discovered that Pb_2CrO_5 film has optical electromotive force effects[3] and photoconductive effects[4] in the visible light region. Optical electromotive force effects can be used in a light position detection device, but its effective measuring range is comparatively narrow at present. Our research tried to utilize this photoconductive effect as a means to expand the effective measuring range, and this article reports the results. It uses characteristics in which resistance is changed by the illumination position of light. Since electricity consumption is small--even in the case of a large area--because the resistance of the material is high, it becomes possible to make fine electrodes and to improve resolution.

2. Composition of Device and Experimental Method

The device is made by the evaporation of the electrode pattern Al shown in Figure 1 to Pb_2O_5 film on a glass substrate. When the surface of the device is illuminated through a 2-mm wide and 10-mm long slit, resistance change occurs in proportion to the illuminated area by photoconductive effect corresponding to the illumination position of the light. As shown in Figure 2, the device is divided into input resistance R_1 and returning resistance R_2 sections, and output change is measured using the reverse amplification circuit. When the ratio of photoconductive current to dark current is not large, output voltage changes almost linearly with the illumination position of the light.

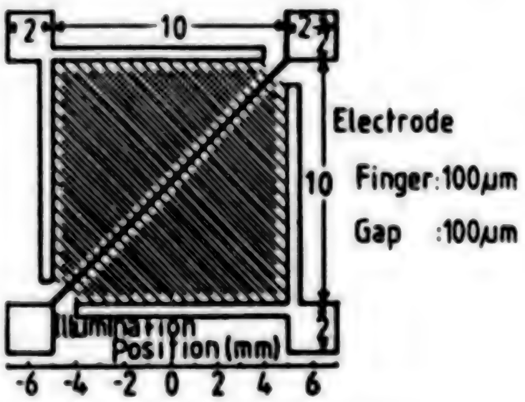

Figure 1. Electrode Pattern

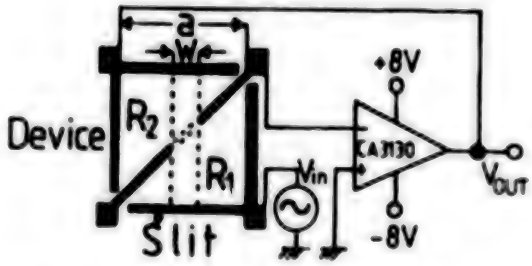

Figure 2. Measuring Circuit

Direct current and alternating current are both used to impress voltage to the elements. In alternating current driving, the peak value of the output current is measured because the measuring time can be shortened and the reproductivity of the measured values can be heightened.

In the circuit shown in Figure 2 it is necessary to monitor light intensity at all times because output changes, albeit slighrly, if light intensity changes. Light intensity dependency can be offset by dividing the two

groups of photoelectric current depending on light intensity. Figure 3 shows a light intensity correction circuit designed for this purpose. If the electric current moving in resistances R_1 and R_2 is made I_{R1} and I_{R2}, detection of the position becomes possible. Output dependency on light intensity can be corrected by dividing $I_{R1}-I_{R2}$, which contain factors of the slit position, by $I_{R1} + I_{R2}$, having only light intensity dependency.

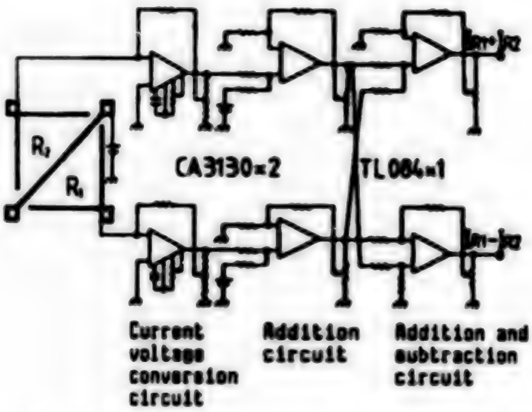

Figure 3. Light Intensity Correction Circuit

3. Results of Experiment

Figure 4 shows the measurement results of the relationship between light illumination position and output signal (Vout) when a sine wave of $4V_{p-p}$ and 50 Hz is impressed as an input signal. Linear error is about 4 percent and the effective measuring range is about 7 mm.

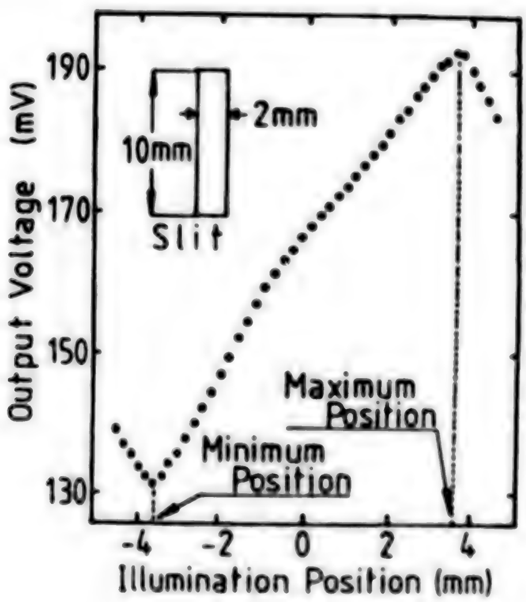

Figure 4. Relation Between Illumination Position and Output Voltage

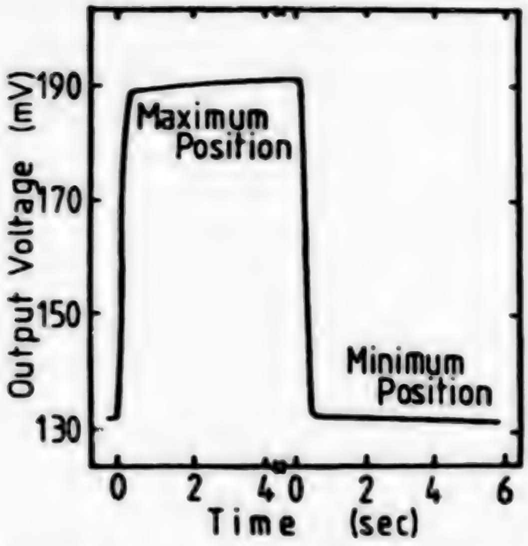

Figure 5. Time Response of Output by Change of Illumination Position

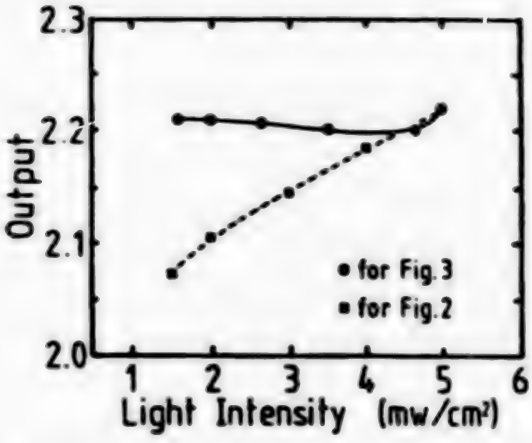

Figure 6. Relation Between Light Intensity and Output Voltage

Figure 5 shows the time response waveform for output when the light illumination position in Figure 4 was moved from the minimum position to the maximum position and vice versa. It took about 0.3 second to increase output voltage and 0.25 second to decrease it. This includes moving time and the influence of drift, but these can almost be ignored. Figure 6 shows the light intensity dependency of output voltage obtained by use of the correction circuit shown in Figure 3 in a condition where input voltage is fixed at 9.46 V and the slit is fixed at a position 2 mm to the right of the center of the device. In comparison to the use of the circuit in Figure 2, light intensity became almost constant within a scope of 1.5 - 5 mW/cm^2 through the use of a correction circuit, and the dependency on light intensity is improved.

4. Conclusion

A light position detection device was made by using the photoconductivity effects of Pb_2CrO_5. The electric current consumption of this element is very small. Its characteristics are consistent with its resolution and its effective measuring range. We will try to further improve its resolution and to transform its output into FM signals.

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20155/9365

Improvements Continue on the JT-60

43062098a Tokyo GENSHIRYOKU SANGYO SHIMBUN in Japanese 9 Jun 88 p 1

[Text] At the Naka Research Center of the Japan Atomic Energy Research Institute (JAERI), work continues on high performance improvements on the Critical Plasma Test Device, the JT-60. There are three main projects for high performance experimentation (Phase 1): installation of a divertor on the bottom of the vacuum container, improvement of the power source to strengthen plasma current (high efficiency current driver), and the new installation of a solid hydrogen fuel injection device. JAERI has already attached the divertor to the bottom and completed construction of the solid hydrogen fuel injector and will continue work on the high efficiency current driver in the future.

JEARI achieved a critical plasma condition in September of last year and is presently at the stage of taking this plasma research in a more high performance direction.

The first phase of the high performance testing will consist of three items: 1) the positioning of the divertor coil on the bottom of the vacuum container, 2) improvement of the power source to strengthen plasma current, and 3) the addition of a device for injecting solid hydrogen fuel (plates).

The divertor is a magnetic field clasp which prevents the plasma from touching the walls. The divertor was originally placed on the side of the container and JAERI is testing its placement on the bottom.

The plate injection device directs solid granules of hydrogen (plates), the fuel, into the center of the plasma using compressed gas in order to increase plasma density.

The high efficiency current driver drives the plasma current at high frequency in order to heat the plasma.

JAERI has already completed the plate injection device and work on attaching the divertor. They will work on the installation of the high efficiency current driver in the future and completion is expected in the last half of this year.

In regard to further efforts on behalf of the JT-60, JAERI has begun an on-

going developmental consolidation of their various computer programs for critical plasma test analysis and they plan to investigate problems associated with converting from discharge gas to deuterium. Furthermore, after completing this present rebuilding, JAERI will begin its Phase 2 high performance improvements; it will enlarge the cross-section (length) by completely replacing the JT-60 vacuum container. They hope to begin testing by the middle of 1990.

13008

Chemical Enrichment Evaluation Committee Established

43062098b Tokyo GENSHIRYOKU SANGYO SHIMBUN in Japanese 9 Jun 88 p 1

[Text] On 7 June the Ministry of International Trade and Industry held the first meeting of the Committee to Evaluate the Chemical Method of Uranium Enrichment (committee chairman: Keiichi Oshima, Professor Emeritus at Tokyo University).

For the rest of this year, the Evaluation Committee will gather together the research on the chemical method of uranium enrichment which Asahi Chemical performed as a part of MITI's subsidy program. They intend to evaluate research results achieved heretofore and to study how best to deal with it in the future.

The chemical method of uranium enrichment takes advantage of the fact that when highly stable hexavalent and tetravalent uranium are put into solution together, uranium 235 favors the hexavalent slightly, about one part in one thousand. Asahi Chemical has successfully established a "super method" which enables, within a single column, the regeneration of the oxidizing agent which accomplishes the addition and removal of the uranium 235 resin.

Asahi Chemical has been using this super method in a model plant (column height three meters X column diameter one meter). In Dec 1986 they began testing at the model plant and in Jul 1987 in preliminary tests they successfully extracted approximately three kilograms of 1.5 percent uranium. In Sep 1987 they performed tests involving the continuous extraction of enriched uranium. For approximately one month in March and April of this year they performed continuous operation and "confirmed three percent enrichment."

The committee has decided to begin with a technical evaluation of these results and to perform a study comparing them with those of other enrichment techniques. They hope to perform a broad study in regard to what should happen in the future, including the directions that research will proceed with joint electric power research. After these studies they will issue an interim report in August and a final report at the end of this year.

13008

Atomic Power Plant Breaks the 300 Billion KWH Mark

43062098c Tokyo GENSHIRYOKU SANGYO SHIMBUN in Japanese 9 Jun 88 p 1

[Text] It has been announced that at 3:15 p m on June 1st, Tokyo Electric Power's Fukushima Number One Plant (BWR, total output 46.96 million KW) recorded its 300 billionth KWH of total power generation output.

This is the second highest in the world, following Canada's Bruce Atomic Power Generating Plant. This is equivalent to approximately 72 million kiloliters of fuel oil.

Looking at Fukushima Number One's experiences up to now, its first unit (460,000 KW) was brought on line in November 1970. In March 1979 its total output reached 50 billion KWH and in March 1981 reached 100 billion KWH. It broke the 200 billion KWH mark in November 1984.

When compared to Japan's total atomic energy power output, it is equivalent to approximately 1.6 years of 1987's total ouput of approximately 1867 billion KWH. It is equal to about 23 percent of Japan's all-time output of 1.3172 trillion KWH (through the end of April).

When its units are viewed separately, Unit One's total is 34 billion KWH (11 percent), Unit Two's is 52.8 billion KWH (18 percent), Unit Three's is 56 billion KWH (19 percent), Unit Four's is 48.8 billion KWH (16 percent), Unit Five's is 48.8 billion KWH (16 percent), and Unit Six's is 59.6 billion KWH (20 percent).

13008

Atomic Energy Safety Conference Held

43062098d Tokyo GENSHIRYOKU SANGYO SHIMBUN in Japanese 9 Jun 88 p 2

[Text] On 2 and 3 June the "Twenty First General Conference on Atomic Energy Safety Research," sponsored by Atomic Energy Safety Research Association, was held at the Zenkyoren building in Hirakawamachi in Tokyo. The topic for discussion of the first day of the conference was "Recent Trends in Radiation Safety in the United States and Their Main Points of Discussion." Special lecturer was C. B. Meinhold, assistant chief of the International Radiation Protection Society. During his presentation, he outlined the present situation in radiation protection in the United States in light of Publication 26 from the International Committee on Radiation Protection (ICRP). In particular he emphasized that "in regard to radiation limits for personnel working on the atomic power generation side, we must consider individual work conditions and set upper limits for safe ranges on the life-scale."

Following this a panel discussion was held on the subject, "Future Hopes for Radiation Protection."

During this discussion, Mr Matsudaira, the head of the National Institute of Radiological Science, stated that in regard to the reevaluation of radiation amounts being performed jointly by the U. S. and Japan, "It is important to make composite predictions about radiation amounts and to include the new data gathered in the almost ten years since the recommendations in the ICRP's Publication 26. In response Assistant Chief Meinhold offered the opinion that, "New data continues to accumulate and in the wider viewpoint including practical radiation equivalency reevaluation, we have arrived at a point wh we must push ahead with the reconsideration of radiation evaluations."

They then moved on to discussion points concerning radiation safety PA problems over which public concern has increased since the Chernobyl accident. The comment from Kusama assistant professor at Tokyo University was that "It is important to balance the relationships among government, workers handling radiation, and the general public in regard to their influence on the direction of radiation safety. The role of employees as regulators will be important."

During this discussion, S. Takashima, assistant chief of the Atomic Energy Safety Analysis Center stated that "To reduce mistakes by people, it will be necessary to study human behavior." While emphasizing the importance of research on the human factor, he also pointed out that from the standpoint of preventing the spread of trouble, "Research into man/machine interfaces and accident mangement will be especially important."

In regard to man/machine interfaces, after exploring the relative apportionment of roles for men and machines, where to promote automation, etc, he offered the opinion that "It will be important to construct a data base, both within and outside of so-called human error." In regard to accident management, he pointed out that "Along with the perfection of accident scenarios, it will be necessary to establish assistance systems using the introduction of AI (artificial intelligence)."

After this, K. Sato, assistant chief of JAERI's Tokai Research Center, presented his views. He pointed out that, "In safety research up to now, as represented by LOCA (loss of coolant accident) studies, substantive concrete answers have been sought, but (safety) research in this sense has come full circle," and he then emphasized that "In the future we will have to go one step further than the substantive, phenomenal research of today to systematize our studies."

13008

Guard Vessel Installed on the 'Monju'

43062098e Tokyo GENSHIRYOKU SANGYO SHIMBUN in Japanese 9 Jun 88 p 2

[Text] Construction work on the "Monju," the Power Reactor and Nuclear Fuel Development Corporation's FBR prototype (power output, 270,000 KW), has entered its peak phase.

At present construction on the "Monju" is 48 percent or nearly half complete. On 8 to 10 June, as a part of construction inside the reactor housing container, they will install the guard vessel (reactor guard container). The guard vessel covers the lower part of the reactor in order to prevent spills of the sodium coolant in case of damage to the main reactor.

The guard vessel is a cylinder made of stainless steel (SUS304) with an open top and panels attached to its bottom. Its inner diameter is about 7.8 meters, its total height is about 12.7 meters, and the thickness of its plates is 40 millimeters (45 millimeters for the plates on the bottom). Because weight of the main body of the guard vessel is about 175 tons, its total transport weight, including shipping frame, comes to about 470 tons.

On 3 June the "Monju's" guard vessel was shipped from Mitsubishi Heavy Industry's Futami plant. On 8 June it will reach the "Monju" site and within the site it will be transported on a 900 meter (branch line). Then on the 13th it will be taken inside the reactor housing and with preparations continuing, they plan to hang it within the containment chamber on the 18th. Installation will be completed by the end of June.

13008

Solid Waste Press System Developed

43052098f Tokyo GENSHIRYOKU SANGYO SHIMBUN in Japanese 9 Jun 88 p 5

[Text] NGK Insulators announced that it has developed a high compression press system for the volume reduction treatment of non-combustable solids at atomic power generating plants. The first device will be delivered to Unit One of Tokyo Electric Power's Fukushima Number One Atomic Power Generating Plant in December 1989. Methods have been developed to treat radioactive wastes at atomic power generating plants, including metals, insulation, glass, concrete, filters, vinyl chloride, etc. With the recent need to improve the fill efficiency of waste containers (200 liter drums), volume reduction treatment for non-combustable solids has become an important subject. As of March 1987, it has been estimated that about 30 percent of the radioactive wastes stored on sites in all of Japan are non-combustible solids.

The high compression press system developed by NGK Insulators uses a vertical high compression system and was made capable of filling 200 liter drums with non-combustible wastes, compressing them, and then refilling them to 200 liters for higher efficiency. It was also designed to be compatible with handling systems at atomic power generating plants.

Its special features are as follows: 1) Through the use of a "high compression vertical press system" using taper-toothed metal patterns, it is capable of producing high compression pellets which enable refilling 200 liter drums filled with non-combustible solid wastes. 2) In its "high efficiency fill system," compression pellet weights, radioactivity, and thicknesses are computer controlled and thus suitable mixtures are achievable when the drums are filled. 3) Because of its 2000 ton maximum high compression, it can handle even large metal objects, and it can reduce non-combustible solid wastes to approximately one fifth their volume.

They say that they have confirmed vertical high compression performance and over-all system reliability using full-scale proving test equipment.

The equipment specifications for this application include a compression force of about 1500 tons, a volume reduction ratio for mostly metal objects of about three to one and a treatment capacity of about 50 drums per day.

Encouraged by this delivery to Tokyo Electric Power, NGK Insulators has decided to sell to other electric power companies as well.

13008

Toshiba Develops Turbine Control Device

43062098g Tokyo GENSHIRYOKU SANGYO SHIMBUN in Japanese 9 Jun 88 p 5

[Text] The turbine control device developed by Toshiba has been selected by the Science and Technology Agency as one of the "Noteworthy Inventions of 1988."

The device can maintain constant reactor presssure even under temporary frequency increases due to things like transmission line accidents and can prevent the unnecessary shut down of generating stations. As turbines and generators at atomic power stations have been controlled up to now, the turbine control equipment has regulated turbine speed and inlet steam pressure using steam control and turbine by-pass valves. However, during temporary frequency increases due to transmission line accidents, when by-pass valve capacity is exceeded due to the closing of the steam control valve, with existing control devices, atomic reactor pressures exceed regulations and the generating plant has to be shut down.

In contrast, the purpose of Toshiba's new turbine control device is to avoid shutting down the generating station at frequencies as high as those which the facility is permitted, even when there are unusual increases in actual velocity, such as those which exceed the complete opening of the turbine by-pass valve. They say the device contains a functional device which completely opens the turbine by-pass valve when system frequency increases, and then at those times when frequency is at permissible levels, maintains a fixed degree of opening without restricting the steam control valve.

This functional device provides wireless speed control commands for actual turbine speed and after it completely opens the by-pass valve, it maintains a fixed degree of opening without contricting the steam control value when frequencies are at permissible levels. By doing this inlet steam pressure remains constant, needless increases in reactor pressure are prevented, and thus generating plant shut down is avoided.

Moreover, they say not only does the device have a low price, no more than the cost of control equipment improvements, but also that improvements to existing equipment are possible.

13008

NUCLEAR ENGINEERING

Reprocessing Safety Research Plan Summarized

43062098h Tokyo GENSHIRYOKU SANGYO SHIMBUN in Japanese 9 Jun 88 p 6

[Text] Presented here is a summary of the plan for future safety research concerning fuel cycle facilities, beginning with reprocessing facilities, as taken from "The Yearly Plan for Safety Research for Atomic Energy Facilities" (1986-1990), revised by the Committee for Atomic Energy Safety.

Nuclear fuel facilities such as those for fuel processing and reprocessing are an important part of the fuel cycle, and it is thought that as the number and scale of these facilities increases with the future advancement of atomic power generation and the achievement of a fuel cycle in Japan, advances in the technology to improve fuel burnup will also be sought.

In working for the establishment of a fuel cycle in Japan, the government has been the driving force behind the technical development of a nuclear fuel cycle and research into the maintenance of safety at nuclear fuel facilities has naturally been included among these technical developments. Consequently, the government has performed safety evaluations and researched safety improvements at nuclear fuel facilities and has evaluated and applied these results from their respective sides.

Specifically, the Japan Atomic Energy Research Institute (JAERI) has performed research into shielding safety and critical safety which are topics common to all nuclear fuel facilities, research into safety evaluation at reprocessing facilities, and research into the safety of processing and storing the radioactive wastes generated at nuclear fuel facilities. Meanwhile, the Power Reactor and Nuclear Fuel Development Corporation (PNC) has by itself designed, built, operated, and managed fuel processing facilities like the Tokai reprocessing plant; and while doing so, it has become a driving force behind technical developments related to the storage and processing of radioactive wastes. The PNC has performed research into all aspects of safety at reprocessing and plutonium handling facilities and also into safety concerning processing and storing the radioactive wastes generated at nuclear fuel facilities.

Although the government has thus played a central role in safety research at nuclear fuel facilities, in the private sector too, with the finalizing of plans for construction of a large-scale commercial reprocessing facility,

safety research directly concerned with designing a large-scale commercial reprocessing facility and safety research concerning recycled wastes have also been advanced. Moreover, universities have also performed basic research into reducing emissions from radioactive substances and into the processing and storage of radioactive wastes.

In regard to Japanese nuclear fuel facilities, it can be said that from our accumuluated experiences at building and operating existing facilities and as a result of related developmental research, we have basically perfected the knowledge needed to make judgements about the maintenance of safety. However, in light of the ongoing construction within the private sector of reprocessing facilities of much larger scale than those of today and also based on the achievement of new technologies for reprocessing FBR fuel, it will be necessary to actively promote safety research for nuclear fuel facilities with the goals of further improving safety, guiding nuclear fuel facility safety on the basis of construction and operational experiences at existing facilities, perfecting standards, and establishing more rational methods of safety evaluation.

Research Areas Common to Nuclear Fuel Facilities

Research Into Critical Safety

At nuclear fuel facilities, in all technically imaginable cases, policies are practised to keep nuclear fuel substances from becoming critical.

For critical planning safety, analysis calculations have been principally based on critical test data from other countries, but because test conditions and conditions within facilities vary, in actuality, conditions cannot help but be [only] fairly safe.

For this reason in the future, it will be important for Japan to build facilities capable of criticality experiments, to perform research into critical safety, and especially to rationalize and improve the reliability of critical safety management techniques and critical safety planning through the independent gathering of data. Moreover, with facilities like the FBR fuel recycling facility which the government continues to plan, in order to work at rationalization and improving the reliability of critical safety planning, it will be important to push ahead with research concerning critical safety, including joint research with other countries. Specific topics for research include critical safety testing, joint U. S.-Japan critical testing, the development of non-critical measurement methods, and criticality management at plutonium handling facilities.

Research Into Shielding Safety

In regard to shielding safety at nuclear fuel facilities, having designed, built, and operated such facilities, we are in a position where most of the basic data and computer coding needed for safety evaluations has been developed and implemented. In the future it will be important from the standpoint of improving safety at nuclear fuel facilities to push ahead

further with research into enhancements. Specific research topics include neutron shielding and exposure management.

Research Into Accident Management Methods

The accumulation of data and analysis methods, based on fundamental systematic testing and necessary for accident evaluation at nuclear fuel facilities, has been inadequate in Japan and for the most part has been performed overseas.

For this reason in the future, in order to make more rational evaluation possible, in light of the large scale of such facilities, it will be important to perform basic experimentation concerning accident evaluation and to develop and implement data and methods of analysis. Specific research topics include research into source term evaluation of emitted radioactivity during accidents, the development of accident analysis coding for reprocessing facilities, and research into large-scale cell safety.

Research Into Radiation Management and Analysis Measurement Techniques

At existing nuclear fuel facilities like the Tokai reprocessing plant, the necessary radiation management and analysis measurement are already in place and technical development continues on remote and automatic analysis measurement. In the future, it will be important to continue with these technical developments in order to improve nuclear fuel facility safety through the stable management of operations and the reduction of worker exposure. Specific topics include the automation of measurement and radiation control, the development of techniques for remotization, and the development of in-line measurement techniques, along with the development of sensors and radiation resistant materials.

Research Into Operational Management, Maintenance, Repair, and Inspection Techniques

Through the experience of the remote repair of the solvent tank at the Tokai reprocessing plant, we have come to recognize the importance of remote repair techniques.

In the future in order to contribute to the stable operation of nuclear fuel facilities, it will be necessary to more actively increase the reliability of remote maintenance and repair techniques.

It will also be important to confirm the soundness of the principal types of machinery, to continue to develop techniques for inspection during periods of operation so that in case defects do arise, they are immediately detected, and to develop an over-all system of preventative maintenance. Furthermore, it will also be important to investigate the evaluation of operational methods in terms of anti-corrosion safety in regard to repair and inspection techniques.

It will also be important from the standpoint of safety maintenance to continue with research into rack systems which enable the safe performance of remote operations with greater efficiency.

In order to improve safety during facility operation, it will be important to develop a system under which operators are taught and trained to take actions which are appropriate and suitable to the operational situation thus preventing trouble due to operator error before it happens.

Research Areas for Reprocessing Facilities

Research Into Anti-Corrosion Safety at Reprocessing Facilities

Based on the generation of leakage defects in the solvent tank and acid recovery evaporation drum of the Tokai reprocessing plant, inquiries have been made into the cause of the defects, as have investigations into the materials and the way they were manufactured, and procedures have been established based on these results.

In the future in order to promote the establishment of anti-corrosion evaluation standards and the further improvement of anti-corrosion safety, it will be especially important to push ahead with research into anti-corrosion safety in manufacturing methods, centering on materials and welding processes and including new materials with hypothesized uses.

Research Into Safety in the Reprocessing Process

Safety in the reprocessing process has already basically been established, but it will be important to continue with research into safety improvements and evaluation for reprocessing processes in light of the application of new machinery and the reprocessing of FBR fuel and high burn-up fuels hypothesized for the future. Specific topics include research into repair techniques and evaluation of the aerosol condition during fuel assembly/disassembly using laser beams, safety research into the dissolution of spent fuel, safety evaluation tests into actions during unusual operations in the extraction process, research into radiation damage to reprocessing extraction solvents, research into hydrogen generation during the reprocessing process, and the development of simulation coding for the reprocessing process.

Research Into Lowering Emissions From Radioactive Substances From Reprocessing Facilities

Heretofore, in order to lower emissions from radioactive substances at reprocessing facilities, recovery techniques have been developed for elements like crypton and iodine. There has also been ongoing research into the applicability of emissions lowering techniques to large-scale commercial reprocessing facilities.

In the future it will be especially important to rive to continue technical developments for emission reduction and to further research into the safe storage of the radioactive substances recovered. Specific topics include the development of techniques for removing and storing radioactive iodine and the development of techniques for lowering tritium emissions.

Research Into Systematizing Safety Data at Reprocessing Facilities

The Tokai reprocessing plant is Japan's only reprocessing facility and valuable technical data has been gathered through its design, construction, and operation. In the future it will be important to systematize this data and to apply it to safety design and evaluation at reprocessing facilities.

Research Areas for Plutonium Handling Facilities

Research Into Safety at Plutonium Handling Facilities

Plutonium handling facilities like plutonium development and manufacturing facilities and plutonium conversion facilities continue to be developed and constructed under PNC leadership, and safety research has advanced along with these technical developments.

In the future while accumulating a record of safe operation at these facilities and keeping in mind its application to large-scale private sector plutonium facilities, it will be important to continue research into plutonium containment characteristics and testing to verify the over-all safety of plutonium handling facilities.

Research Areas for the Treatment and Storage of Radioactive Waste

Research Into Safety During the Treatment and Storage of High-Level Radioactive Waste

In order to assist with safety improvement and evaluation for solidified storage and vitrification facilities for high level wastes, in the future it will be important to continue with research into the reliability of pretreatments for liquid wastes, research into safety measures for glass melting ovens, research into improvements in the ability to remove radioactive substances from off-gases, and research into the safety of treating and storing high level wastes.

It will also be important to push ahead with 1) research into the safety of treating and storing TRU wastes and 2) research into the safety of treating and storing radioactive wastes (other than TRU and high-level wastes) from reprocessing facilities.

13008

Advanced Materials Applications for Nuclear Power Plants

Light Water Reactor

43067590 Tokyo NIPPON WELDING ASSOCIATION AND NUCLEAR RESEARCH COMMITTEE in Japanese 18 May 88 pp 3-16

[Article by Koji Terabayashi, Institute for the Development of the Next-Generation Machinery and Equipment for Nuclear Power Plant, Technical Research Association: "Applications of Advanced Materials for Upgrading Light Water Reactors"]

[Text] 1. Foreword

As of FY 1987 (1 January 1988), nuclear power reactors in commercial operation in Japan numbered 35, with an installed capacity of 27.88 million kW in generating power (fourth place internationally in both categories). Since overtaking oil-fired power generation in FY 1986 to become the leading producer of electricity, nuclear power generation has achieved a great mark, for the first time accounting for more than 30 percent (31.7 percent, sixth place internationally) of Japan's total output of electricity. While contributing to reduced oil consumption (a reduction of about 44 million kl), the importance of nuclear power generation in Japan has all the more increased with its role in promoting the growth of the economy and industry as well as in elevating the people's livelihood. As a result, increased reliability of nuclear power generation is now sought.

There may come a time when fast breeder reactors become the predominant means of power generation, but light water reactors apparently will continue to be the mainstay for some time to come. Although LWR technology is believed to have reached a stage of maturity, further sophistication of the technology is anticipated to enable it to keep playing a principal role in supplying electric power.

The author describes the applications of advanced materials for upgrading LWR technology and the current state of research and development in that field.

2. History of Developments of Materials for LWR Equipment and Components in Japan

With respect to the research and development of materials for LWR equipment and components in Japan, much credit has to go to those materials which have a long history of use in thermal power plants in the United States and Japan and which were manufactured based on proven technologies. Light water reactors, however, have experienced their share of initial-stage problems, such as stress corrosion cracks and the corrosion of heat-transfer pipes in steam generators (SG). Therefore, since about 1970, efforts have been stepped up for research and improvements, aimed at increasing reactor reliability, safety and economics as well as at reducing the workers' exposure to radiation.

As Table 1, "Examples of Changes in LWR Materials," shows, R&D efforts toward improving the materials used in various equipment and components have been steadily promoted, aimed at their applications in commercial reactors.

Other R&D efforts for improvement, in addition to those listed in Table 1, include the following:

(1) Raising the abrasion resistance of the latch arm edge of the claw axis drive in the PWR control rod drive mechanism by coating it with chromium carbide (Cr_3C_2). This procedure has not only enabled it to cope with increases in the frequency of insertions and extractions of control rods, but is also expected to contribute to reductions in worker exposure to cobalt-60 radiation since the chromium carbide-coated material contains less cobalt than paddings of the currently-used stellite (alloys containing about 65 percent cobalt).

(2) Making the PWR fuel handling and transfer equipment maintenance-free through application of silicon nitride (Si_3N_4) to its underwater bearings and simplifying the drive mechanism.

(3) Applications of ceramics, such as alumina, to the reactor wall lining of radioactive waste incinerators.

(4) Applications of ceramics to sensors and connectors in electrical and measuring instruments, as well as insulating materials.

(5) Applications to flame retardant insulating cables, such as electric and control cables.

Table 1. Examples of Changes in Materials for LWRs (1970–)

Equipment & Component		Changes in Materials	Reason
Primary piping (BWR)		From 18Cr-8Ni stainless steel (SUS304) to low-carbon content, Mo and N impregnated 18Cr-8Ni stainless steel (316 for nuclear reactors).	To increase resistance to SCC.
Steam Generator (PWR)	Heat transfer pipe	From Inconel 600 (Ni alloy) to Inconel 600 (a special heat treatment applied). Use of Inconel 960 planned.	To increase resistance to SCC, pitting, and general corrosion.
Steam Generator (PWR)	Piping support board	From carbon steel to ferrite stai-less steel.	To increase resistance to corrosion.
Steam Generator (PWR)	Steam generator	From low alloy steel Mn-Mo-Ni steel to Mn-Mo-Ni steel (heat treated).	To increase strength by heat treating.
Reactor containment vessel (BWR)		From carbon steel to high tensile steel. (1) To increase tensile strength. (2) To increase fracture toughness.	To increase strength as vessel size increases.
Reactor pressure vessel (BWR)		From carbon steel to low alloy steel (Ni-Cr-Mo steel). (1) To increase tensile strength, (2) to increase fracture toughness about 2-fold (shock-absorbing energy value)	1. To increase strength and fracture toughness as vessel increases in size. 2. To increase resistance to embrittlement from neutron irradiation (reductions in P, Cu)
Pressure vessel (PWR)		Low alloy steel (Cr-Mo-V steel). Reduction in Cr content.	To prevent cracks in weld seams.

PLR pump main axis (BWR)	From 18Cr-8Ni stainless steel to 18Cr-8Ni stainless steel (Nb, Mo and V impregnated)	To increase resistance to SCC. To increase strength.
Bleeding system piping (PWR)	From carbon steel to low alloy steel (L-1/4Cr-1/2Mo, etc.).	To increase resistance to decreasing padding.
Control rod guide roller (BWR)	From stellite (cobalt alloy) to non-cobalt alloy (Ni alloy).	To reduce worker exposure to radiation.
Low-pressure turbine blade (BWR) (final stage)	From stellite padding to frame hardening (hardening treatment).	To reduce worker exposure to radiation.
Low-pressure turbine blade (PWR)	From 12Cr steel to precipitation hardening stainless steel (17Cr-4Mo steel).	To increase rigidity gas reactor increases in size (1.10 million kW).
R W condenser	From 18Cr-8Ni to Inconel 625 stainless steel (Ni-base alloy).	To increase resistance to corrosion.
Condensate filter (BWR)	From filtration-assisting agent to hollow fiber films.	System simplification and volume reduction of waste.
Condenser capillary (BWR, PWR)	From aluminum brass to titanium tubing.	To increase corrosion resistance.

3. Japanese Plans for Applications of Advanced Materials to Upgrade Light Water Reactors

3.1 Proposals for Applications of Advanced Materials to Upgrade Light Water Reactors

In its August 1984 interim report, the Subcommittee on Upgrading Light Water Reactor Technology, established within the Atomic Power Division of the Advisory Committee for Energy (in February 1984), forecast that light water reactors would continue to be the mainstay of the electric power supply for a long time to come and that their importance would increase furterh. As measures for achieving "increased lifetime power generation" and "enhanced lifetime plant operability," the report places priority on extending the plant life and achieving a high plant operability, listing such goals as "elevating the reliability of machinery and equipment," "raising the efficiency of periodic inspections," "extending the period during which a plant is continuously operated," and "increasing the ease of plant and equipment maintenance" and proposes the use of "advanced materials" as one of the measures for achieving the objectives.

Next, based on the above report, in March 1986 the Atomic Power Division of the Advisory Committee for Energy listed tasks for the technical development of the existing and next-generation type of light water reactors, calling for the pursuit of further enhanced reliability and economics, as well as for the realization of inspection-free and maintenance-free operations of machinery and equipment through the use of "advanced materials."

3.2 Research Project for Advanced Materials Applications and Start of "Nuclear Equipment Research Institute"

To conduct studies of the objectives described in paragraph 3.1 and their feasibilities, the "Prefeasibility Study Committee for Applications of Advanced Materials" was established within the Ministry of International Trade and Industry (MITI) for April-October 1985, and based on the results of the committee's study, the "Nuclear Equipment Research Institute" (ANERI) was inaugurated.

Contents of the research by ANERI cover both inside and outside the radiation domain, including such topics as "further improvements in reliability and safety," "reduction in the amount of radiation dosage to which the operator is exposed," "increased efficiency in maintenance work," and "increased plant operating rate"; the targets for research are not necessarily limited to advanced materials but include improved materials as well, and the research there involves examining the feasibility of tapping the specific features of raw materials as seeds that are physically stable to heat or stresses, are chemically superior such as high resistance to corrosion, and have relatively good chances for development in applications designed to meet the needs for electric power demanded of light water reactor equipment in the field. Undertaken as a project under a contract from MITI, this program has led to research being conducted on advanced materials, such as ferrous and nonferrous metals, fine ceramics and polymers.

(1) Research and Development Project for Applications of Advanced Materials by ANERI

In ANERI's development project, the research and development, beginning in 1985, will be conducted over a period of about 9 years on everything from feasibility surveys to verification tests to total evaluations. The advanced materials being researched are scheduled to undergo verification tests during their final stage of development, using an actual nuclear power plant with the cooperation of the plant manufacturers and electric power companies, in order to verify their reliability when used in such demanding products as light water reactor equipment and components, which call for an especially high level of quality control and quality guarantee.

In general, running studies on applications of advanced materials will entail great risks, in addition to costing a lot of money and taking a long time. Consequently, it cannot be denied that undertaking such a project on the part of the private sector alone would involve much difficulty.

In this respect, we believe the ANERI project, which is being aided by the government, is significant.

(2) Organizational Structure of ANERI

The organizational structure of ANERI is comprised of 30 corporate organizations including two neutral organizations, three materials centers, three plant manufacturers and 22 materials manufacturers, with ANERI acting as the secretariat. The following 30 organizations or corporations comprise the membership: Ishikawajima-Harima Heavy Industries Co., Ltd., Kawasaki Steel Corporation, Metallic Materials Research and Development Center, Industrial Research Institute Japan, Japan High Polymer Center, Kobe Steel Corporation, Showa Denko K.K., Nippon Steel Corporation, Sumitomo Metal Mining Co., Ltd., Sumitomo Metal Industries, Ltd., Sumitomo Electric Industries, Ltd., Sekisui Chemical Co., Ltd., Daido Steel Co., Ltd., Denki Kagaku Kogyo K.K., Central Research Institute of the Electric Power Industry, Toshiba Corporation, Nisshin Steel Co., Ltd., NGK Insulators, Ltd., Nippon Mining Co., Ltd., Nippon Kokan K.K., Nippon Seikosho K.K., NGK Spark Plug Co., Ltd., Hitachi Chemical Co., Ltd., Hitachi Metals, Ltd., Hitachi, Ltd., Japan Fine Ceramics Center, Bridgestone Tire Co., Ltd., the Furukawa Electric Co., Ltd., Mitsubishi Metal Corporation, and Mitsubishi Heavy Industries, Ltd.

4. Current State of R&D for Applications of Advanced Materials at ANERI

The author believes individual users of electric power and plant manufacturers are also engaged in the R&D of advanced materials or improved materials for their possible applications to light water reactor equipment and components, but described below is the current state of R&D at ANERI.

Descriptions are given in the order of the arrangement of research themes listed in Table 2, "Items for Research and Development at ANERI."

4.1 Pumps

(1) Main Shaft, Casing, Impeller and Submerged Bearing of Seawater Pump (Figures 1 and 2)

a. Main Shaft, Casing and Impeller (applications of improved stainless steel or two-phase stainless steel)

At present, 316 stainless steel, etc., is used in the main shaft, casing and impeller in the seawater pump for cooling the auxiliary machinery to the vertical shaft. However, these steels are vulnerable to pitting or crevice corrosion by seawater. Therefore, the development of materials highly resistant to corrosion is awaited.

ANERI has, so far, successfully developed an improved type of stainless steel, high in N content, that also contains Mo, which makes it possible not only to reduce the use of expensive Ni, but also is highly anticorrosive, equivalent to Inconel 625, and of a two-phase stainless steel rich in Mo, which not only can be cast into large products but also has a high level of resistance to pitting. The two types of stainless steel have proved to have the edge over conventional materials in terms of strength and resistance to pitting.

After letting the two types of stainless steel go through tests to see if they can be fabricated into large products for practical use and if they are economically competitive with existing materials, ANERI plans to subject them to verification tests as soon as possible.

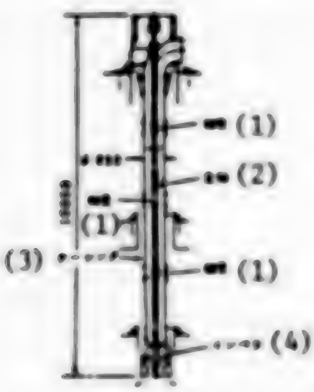


Figure 1. Circulating Water Seawater Pump Arrangement

Key:
1. Bearing
2. Main shaft
3. Casing
4. Impeller

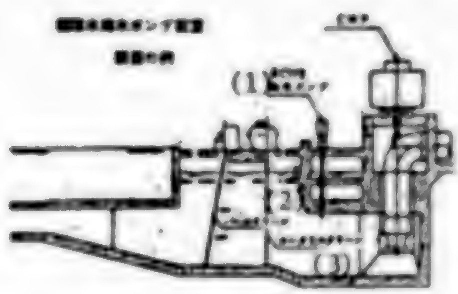


Figure 2. Pump's Cross Section

Key:
1. RCWS Seawater pump
2. Bar screen
3. Rotary screen

b. Submerged Bearings (applications of fine ceramics)

At present, submerged bearings are made of either rubber or phenol resin and are easily worn out. In order to extend their life and simplify the lubricating water supply system during start-up, ANERI is engaged in developing submerged bearings made of fine ceramics.

The raw materials used were alumina (Al_2O_3), silicon nitride (Si_3N_4) and silicon carbide (SiC). Parts manufactured by sintering small test pieces at normal temperatures showed favorable characteristics. Plans are being made to conduct studies on the following subjects: characteristics under the conditions of an operating reactor, such as resistance to abrasion by underwater sand and resistance to shock caused by the vibration of the axis, characteristics of the non-water injection time (30 seconds) before water begins to spring on its own pressure, the manufacture of full-scale submerged bearings and the design of the pump itself.

(2) Mechanical Seals on Pumps for Reactor-Coolant System

a. Mechanical Seal for Pump on BWR Recirculating System (application of short fiber FRM or C/C composite) (Figure 3)

A contact-type mechanical seal (ϕ200 mm), the device in use now, has sintered carbon on its fixed side (the rotating side has a superhard alloy). This has resulted in shorter intervals of replacements during inspections and the relatively long time of 1 hour to complete the replacement work. Therefore, if only from the perspective of reducing the workers' exposure to radiation, the development of long-life mechanical seals is awaited.

The ANERI research for the development of alternatives to sintered carbon has led to the development of fiber reinforced metals (FRMs), which were manufactured by impregnating matrices of Al or Fe-base alloys with short fibers of Al_2O_3 or SiC by the semi-melt and coagulation method or the molten bath forging method, and carbon-fiber reinforced carbon composites (C/C composites).

Studies are currently being conducted of what effects these alternative materials have on their opposite material (the superhard alloy on the rotating side), as well as of what characteristics these materials have when used as seals and how to manufacture mechanical seals out of them. Of the two types of alternative materials, FRMs are characterized by their high strength and toughness, so the emphasis in research is placed on how to protect their counterpart from wear and tear, while in the latter category of products the emphasis is placed on how to manufacture leak-proof seals out of these composites, by such means as braiding the fibers, because seals based on the composites have higher leakage rates than those made of conventional materials.

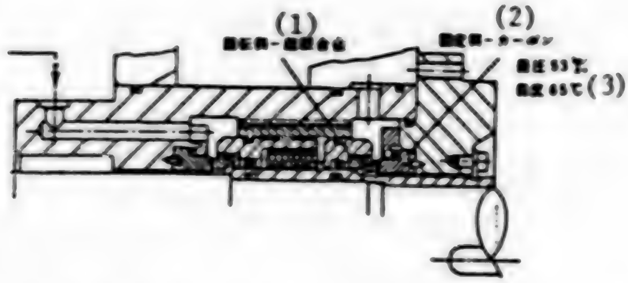


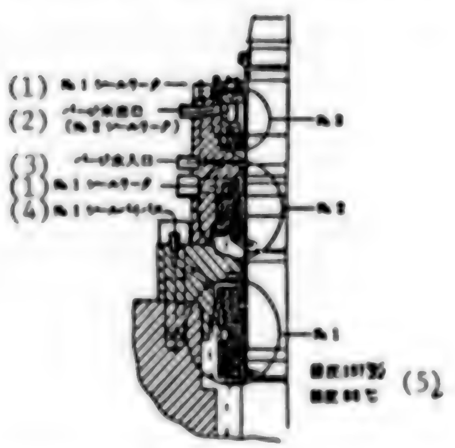
Figure 3. Mechanical Seal for Pump on BWR Recirculating System

Key:
1. Rotating side - ultrahard alloy
2. Fixed side - carbon
3. Differential pressure 53 kg/cm^2
   Temperature 65°C

b. Mechanical Seal for Pump on PWR Primary Coolant System (application of fine ceramics) (Figure 4)

The mechanical seal targeted for development is a non-contact type seal (ϕ312 mm) in the first stage on the high pressure side. Although it is usually free from contact-and-slide motions, the seal often is forced into contact conditions and rubbed against by erroneous operations during the start-up or stoppage of the plant. The material currently being used for the seal, Al_2O_3, cannot withstand such motions, so the development of materials that can withstand light contact-rubbing motion is awaited.

ANERI is developing SiC and Si_3N_4 as alternatives to Al_2O_3, and these materials have shown excellent basic characteristics with respect to resistance to abrasion, etc., posing bright prospects for commercialization. Alternative materials have already been developed in the United States and Europe (details about their longevity are unknown).



Key:
1. No 1 seal leak
2. Purge water outlet (No 2 seal leak)
3. Purge water inlet
4. No 1 seal bypass
5. Differential pressure 157 kg/cm^2
   Temperature 88°C

Figure 4. Mechanical Seal for Pump on PWR Primary Coolant System

(3) Casing and Impeller of Pump on Radioactive Waste Treatment (RW) System (applications of ceramic coatings)

To improve the corrosion resistance characteristics of the impeller and casing, which are currently made of stainless cast steel, in a condensed waste liquid (high temperature aqueous chloride solution) and extend their life, development of the technology to coat three-dimensional, complex-shaped pump elements with ceramics of the zirconia group by plasma sputtering is under way.

(4) Packings, Gaskets and O-rings for Pumps

a. Packings and Gaskets for Pumps (applications of C/C composites and FRTP)

Packings and gaskets for a pump are mainly made of asbestos or graphite, but they need to be replaced after several years' use (some plants replace them earlier than others) for such reasons as the deterioration of the raw materials due to heat. Efforts are being made to develop longer life and asbestos-free packings and gaskets.

Developmental work is focused on C/C composites and fiber reinforced thermo plastic resins (FRTP) as candidates for alternative materials.

1) Since existing C/C composites are of a hard type, they cannot be used as the materials for packings and gaskets that must be able to rebound from compression. Therefore, developmental work is under way to develop a structural composite of flexible, expansive graphite and carbon fibers for use as the material for pump gaskets that can withstand 210°C, a compressive force of 173 kg/cm^2, and will last for 10 years.

2) The biggest problem with FRTPs is how to make them heat-resistant, so the goal is to develop pump packings for low temperature use (up to 50°C) that will have a life of 5 years.

b. O Rings for Pumps (applications of modified EP rubber)

EP rubber is currently being used as the material for O rings for pumps. In order to develop O rings with a durability 1.5 times as high as their existing counterparts, work is being undertaken to develop a modified rubber, which will have a proprietary mix of the raw material rubber and compounding ingredients and will be manufactured in a process involving kneading forming and bridging.

4.2 Valves

1. Valve Seat (Figure 5)

Stellite No 6, a cobalt alloy characterized by a superior resistance to abrasion and galling, has been used in the valve seat. As the valve opens or closes, the valve seat is worn away or is eluted. This causes the

cobalt (Co) to be taken into the reactor water, where it is activated to transform itself into cobalt-60, subjecting the operator to possible exposure to an increased dosage of radiation. Therefore, the development of alternative materials to stellite is anticipated. The development of the following stellite-alternative materials is either under way or on the drawing board:

(1) Surface Hardening Materials (applications of Ni-base alloys, Fe-base alloys, and ceramic coatings)

a. Applications of Ni Alloys

In this developmental work, alloys with properties close to those of stellite are selected out of existing low-cobalt-content materials, then alloying elements are added that will contribute to improving the alloys' properties as a material for the seat and to the alloys' machining. A powder padding welding method of two kinds of alloys of Ni-Cr-W and Ni-Cr-Mo-Nb by PTA (plasma transfer arc) has been selected, and tests are now in progress to see changes in the amounts of the component elements of the alloys.

Future plans call for subjecting the products to testing to see if they satisfy the requirements and conditions demanded of a valve seat, such as anti-galling characteristics.

In the United States and Europe, research and development is under way on "Colmonoy" (brand name).

b. Applications of Ni-base Alloy and Fe-base Alloy in Amorphous Structure

Amorphous alloys are non-crystalline, are extremely hard and have a high resistance to corrosion. Therefore, basic studies are being made of methods for using amorphous forms of Ni alloys and Fe alloys, which can be formed relatively easily into amorphous structures, as surface hardening materials. In these methods, Ni- and Fe-alloy powders are coated on a base metal by PTA sputtering for padding, and the coated surface is bombarded with laser irradiation to transform it into an amorphous state.

With this process, there are limits to how thick the padding can go and, moreover, the alloys may recrystallize due to high temperatures (temperatures below about 450°C are considered trouble-free). Basic physical properties of the coated metals, including properties of the substrate coating layers, are being evaluated to determine their applicability as a material for making the seat.

c. Applications of Fe-base Alloy

A Fe alloy, rich in Mn, which was developed by ANERI as a turbine erosion shielding material, is highly resistant to erosion. Work has been started to develop the alloy into a surface hardening material for the valve seat with a strength as high as or above stellite No 6.

Studies of Fe alloys, among others, have been conducted extensively in Europe, and the products are being marketed under the brand names of "Senium Z20, 36."

d. Applications of Ceramic Coatings

(a) Coatings of Titanium Nitride (TiN)-Titanium Chromium (TiCr)-Ceramics

A TiN-TiCr coating on a valve seat applied by the plasma arc ion deposition method enables higher values in terms of adhesiveness and higher temperature hardness to be obtained than those for the existing stellite valve seat. Studies are being made of the product's applicabilities as a seat material with respect to how to obtain a thick layer of coating, its resistance to baking and galling as well as elution under high temperature and pressure.

(b) Zirconium Ceramic Coatings

Under this process, ceramic powders such as zirconium (ZrO_2) and chromic acidare, are mixed into a slurry. The slurry is coated on a seat material and sintered. This cycle is repeated to obtain a hard and compact coating. With this technique there are limits to how far the film thickness can go and, furthermore, the different elongation and strain rates between the base metal and coating, it has been judged, cannot satisfy the demanded requirements. Consequently, this research has been terminated.

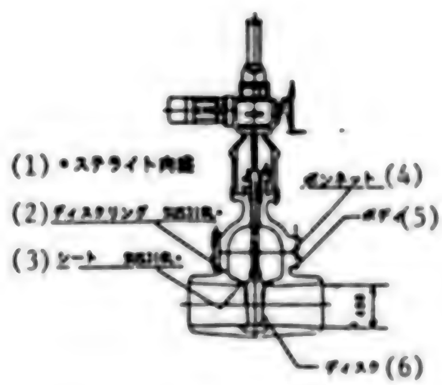


Figure 5. Valve seat

Key:

1.	Stellite padding	4.	Bonnet
2.	Disk ring	5.	Body
3.	Seat	6.	Disk

(2) Diaphragm Valve Seat (applications of modified rubber) (Figure 6)

The rubber diaphragm valve seat is made up of rubber and reinforcing fibers, but it suffers from deterioration as a result of repeated operation and heat. Consequently, development of a longer lasting seat is anticipated.

In this research, efforts have been made to develop modified rubber and reinforcing fibers in a bid to come up with a valve seat for PWRs that will last 1.5 times longer than the current one. Modified EP (ethylene propylene) has been selected for the former, and efforts are being made to improve the bridging and reinforcing agents. Aramid fiber has been selected as the reinforcing fiber, and it is undergoing tests for flexing resistance.

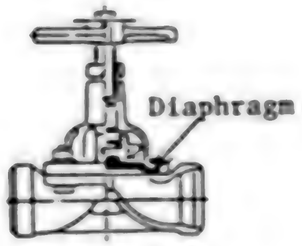


Figure 6. Diaphragm Valve Seat

(3) Valve Axis Seal Grand Packing (applications of C/C composites) (Figure 7)

Taking advantage of their respective advantages, a combination of asbestos and graphite has been used in the seals of the valve axis, but they need to be replaced periodically since they deteriorate with time.

The work of replacing these seals causes the people involved to suffer exposure to an increased dosage of radiation, so development at ANERI is being promoted to extend the life of these seals and manufacture them asbestos free.

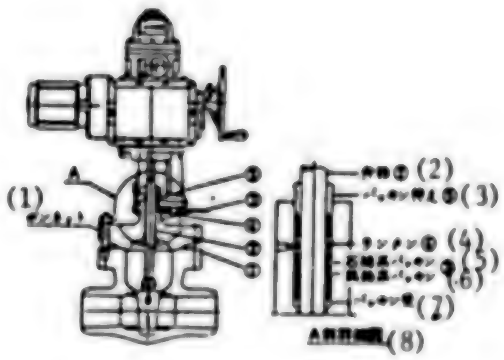


Figure 7. Valve Axis Seal Grand Packing

Key:
1. Bonnet
2. Valve rod
3. Piston follower
4. Ianthunum
5. Asbestos packing
6. Graphite packing
7. Packing receiver
8. Expanded diagram of a section

C/C composites are thought to be candidates for alternative materials, but their problems involve high hardness. Therefore, studies are being made of structural compounding, as in the case of pump packings, between flexible graphite and carbon fiber. After improving their sealing properties and flexibility, evaluations will be undertaken.

4.3 Piping

1. Seawater Piping

At present, seawater piping, such as pipes for circulating water and seawater pipes for cooling the auxiliary machinery, for a nuclear power plant has, as is the case with a thermal power plant, a lining of polyethylene, tar epoxy or rubber installed on the interior surface of the pipe, but these pipes suffer from corrosion by seawater, the attachment of marine organisms and erosion.

During periodic inspections much effort has been expended to remove marine organisims attached to the interior of the seawater piping, and improvements of the seawater piping at the material level are anticipated.

To meet this requirement, such functional metal composite materials as composite steel pipes (clad or duplex pipes) and fiber-reinforced plastic by filament winding (FRP-FW) piping have been developed, and are being tested for applicability with respect to resistance to corrosion by seawater and the capability of preventing the attachment of marine organisms.

(1) Applications of Composite Steel Pipes

a. Flame Spraying and Rolled Steel: In this method, Cu-Ni ally powder (cupronickel) is plasma sprayed on a carbon steel plate and the carbon steel plate is hot rolled. This process is being developed for laying large-diameter piping (from about 450 mm to 3400 mm in external diameter). For seam welding, a low penetration welder of reverse polarity control is used.

b. Diffused Junction Duplex Pipe: In this method an inner pipe, made of a Cu-Ni alloy that has excellent properties to prevent the attachment of marine organisms and the surface of which has a coil of an insert metal wound around it, is inserted inside an outer pipe of carbon steel and heated for diffusion bonding. This technology is being developed for laying piping of below 250 mm in outside diameter.

High temperature cracks have not been observed on the weld metals as a result of welding-caused dilution of the phosphor in the insert metal, thereby confirming the feasibility of this technique.

c. Hot Rolled Clad Steel Pipe: In this method a flat plate of carbon steel for the outer pipe and a flat plate of Cu-Al alloy for the inner pipe (surface plated) are formed into a composite by the hot rolled

cladding method. The composite is then rolled and fabricated into a clad pipe. This technique is being developed for laying piping of 3,400 mm in outside diameter.

d. Duplex Pipe Through Bonding of Expanded Pipes: In this method the inner pipe of stainless steel, titanium and Cu-Ni alloy is placed inside the outer pipe of carbon steel. The junction is then heated to expand the pipes. The thermal contraction of the outer pipe makes it possible to manufacture a duplex pipe. The technique is being developed for laying piping of about 400 mm in outside diameter.

(2) Applications of FRP-FP Piping

In this research different types of resins, such as vonyl ester resin, are reinforced with glass fibers, which are further impregnated with agents that prevent marine organisms from attaching (non-polluting materials). The objective of the research is to develop a technique for laying piping of about 3,400 mm in outside diameter. Studies are to be conducted on the strength of the piping, as well as on the construction of the pipes and joints.

2. Piping for Radioactive Waste Processing (piping for RW system)

The materials being used at present for making RW system piping in nuclear power plants, SUS316, etc., are fully resistant to corrosion. However, to further increase their reliability and economy, the following R&D projects have been undertaken.

(1) Applying a Ceramic Coating on the Interior Surface of Stainless Steel Piping

In this method a coating of different kinds of ceramics, including oxides (alumina and "chromina"), carbides (chromium carbide and silicon carbide), and nitrides (silicon nitride and titanium nitride), is applied by plasma spraying on the interior surface of L steel pipes of SUS316, the material currently used. This technique is being developed for laying a piping of 150 to 250 mm in outside diameter.

As for the loss in volume through corrosion, this technique has enabled an excellent anti-corrosion capability to be obtained, and the loss (in the case of an alumina coating) has been as small as about one-fiftieth that of SUS316L. Various evaluations are planned.

(2) Applying a Laser-Induced Ceramic-Like Coating on the Interior Surface of Carbon Steel

Stainless steel is expensive. Therefore, in this method, in achieving economy, chromium (Cr), a metal highly resistant to corrosion by a RW system solution high in chloride content, is applied to the interior surface of carbon steel by either wet-type plating or powder spraying, and

the coating is bombarded by laser irradiation to transform it into a kind of ceramic. This technique is being developed for laying a piping system 200 mm in outside diameter.

Under a simulated RW environment, the product thus obtained has shown resistance to corrosion and erosion on a par or higher than that for the material currently being used, and several evaluations are planned.

4.4 Thermal Transfer Machinery and Equipment

(1) Steam Generator (applications of coating of different kinds of ceramics)

Inconel, a nickel-base alloy with superior resistance to corrosion, is used for manufacturing heat transfer pipes (ϕ21) in the steam generator. To further increase their resistance to corrosion, the current research is focused on coating the outer surface with ceramics due to the ease in engineering work.

The CVD method, which enables a compact and highly cohesive layer of coating to be obtained, has been selected as the external surface coating technique, and SiC or Si_3N_4, each receiving attention as a promising ceramic, has been chosen for adoption as the ceramic material. Basic studies are being promoted. It has been confirmed that applying a ceramic coating greatly increases the heat transfer pipe's resistance to corrosion at room temperature. Tests are being undertaken to determine if the film of coating can stably withstand the corrosive environment of high-temperature and high-pressure water (290°C, 70 kg/cm^2), and studies are being conducted on the material quality and coating structure.

(2) Condenser in the Radioactive Waste Processing System (applying a coating of different kinds of ceramics)

The objective of this research is to apply a coating of ceramics, such as SiC or Si_3N_4, to the inner surface of the stainless steel heat transfer pipe, 50 mm in inner diameter, in the condenser to improve the pope's resistance to corrosion. The key to the success of this developmental project is the stability of the ceramic coating layer in high-temperature and highly corrosive waste liquid (150°C, 10 kg/cm^2 of chloride), and feasibility studies are being conducted on the coating method and the ceramic materials, as well as on the technique's prospects for development.

4.5 Control Rod Drive (CRD)

(1) FMCRD Guide Roller (application of SiC, Si_3N_4, Al_2O_3 or ZrO_2 ceramics) (Figure 8)

A large number of various types of guide rollers made of stellite No 3 are used in the FMCRD of the advanced BWR. The objective of this research is to develop abrasion-resistant ceramic guide rollers and put them into practical use so that the use of cobalt, which turns into a radiation

source inside the reactor, will be reduced. The targets for research have been narrowed down to SiC, Si_3N_4, Al_2O_3, and ZrO_2. Various sintered products of these ceramics have been tested with respect to abrasion resistance, sliding properties, andstability in high temperature water, but many problems have been found with respect to, among others, resistance to shock and heat shock (more than 850 shocks in the 50 ↔ 300°C range).

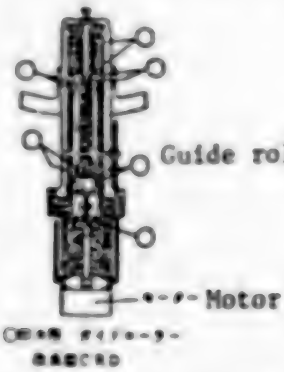


Figure 8. Advanced CRD

(2) CRD Seal Ring (applications of Al_2O_3 and ZrO_2 ceramics)

The CRD in a BWR currently needs to be dismantled and inspected at about 5 year intervals. The factor determining the longevity of the inspection cycle is the periodic replacement ofthe seal ring made of sintered carbon. The development of a ceramic-based seal ring is expected to lengthen the intervals at which the CRD needs to be dismantled for inspection. Sintered bodies of Al_2O_3 and ZrO_2 have been selected and tested for their resistance to heat shock and their stability in high-temperature water. It has been known that ZrO_2 has some problems with respect to stability in high-temperature water, so from now on the research will be focused on high-purity Al_2O_3. After making improvements in such fields as the sintering method, the ceramic will be subjected to tests for performance evaluation.

(3) CRDM Coil Assembler (applications of superengineering plastics)

In the PWR plant the control rod drive system is located above the reactor vessel and activates when an electric current is applied to coils at three different locations in succession. The insulating material currently used for the coils is a sand- and silicon-filled material. One problem is that the insulating material can only withstand temperatures of below 200°C, so a fan is concurrently used for cooling. The development of a coil-filling material that can withstand much higher temperatures would eliminate the need for a fan, thus possibly improving the economy. To that end, research has been conducted on the applicability of superengineering plastics. Polyether-ether-ketone (PEEK) and liquid polymers are currently thought of as promising materials, but these materials involve problems with respect to improving the heat conductivity andthe tendency to get impregnated while being formed into a coil.

4.6 In-Pile Machinery

1. In-Pile Structures (applications of stainless steel low in cobalt content and of controls of cobalt elution) (Figure 9)

Different kinds of stainless steel with cobalt content of 0.2 to 0.05 percent or below, although the cobalt content varies depending on whether the plant is a BWR or a PWR, are currently used for manufacturing in-pile structures. The elution of the cobalt into the reactor water is one of the causes leading to an increase in the amount of radiation, so it is preferable that the materials being used contain as little cobalt as possible. To that end, the following R&D projects have been undertaken.

In the United States and Europe, except for some special cases (less than 0.0003 percent for the fuel grid), the cobalt content is in the 0.2 to 0.05 percent range or below.

(1) Stainless Steel Low in Cobalt Content (applicjtions of improvements of materials and of elution controls)

a. The target is the development of a stainless steel with cobalt content in the 0.01 to 0.001 percent range or lower by restudying the mix of the raw materials. This research has been undertaken for the reason that since removing cobalt while the materials are being dissolved is difficult, research needs to be conducted at the level at which the raw materials are being mixed.

b. This research is aimed at reducing the amount of cobalt eluted by reducing the amount of cobalt content in the stainless steel while increasing its resistance to corrosion. The goal is the development of stainless steel of the austenite, ferrite or two-phase high Ni group, containing 0.01 percent or less cobalt.

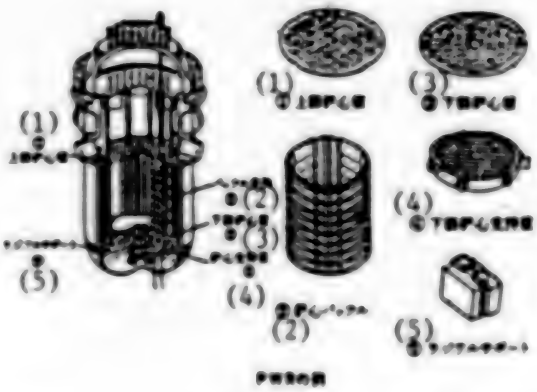
(2) Surface Treatment for Controlling Cobalt Elution (applying an oxidation treatment on the surface of current materials)

In this process the reactor structure materials currently being used, such as SUS304, are subjected to oxidation treatment in high temperature air or steam to obtain the growth of a coat. Compared with the materials used currently, the products thus obtained had a total corrosion elution of less than one-fifth (one-sixth for Co).

The reductions are believed to have been brought about by the formation of a coat that is more minute and stable than a naturally formed one, and the technique's applicability to weld zones and the determination of any effects the radiation domain has on the coat are being investigated.

(3) Ceramics Coating Treatment (applying a coating to the surface of the materials currently being used)

In this method, ceramic powder, such as zirconia (ZrO_2), is mixed with chromic acid to produce a slurry. The slurry is coated on a structural material and sintered. A repetition of this cycle enables a hard and minute coating to be formed. In consideration of the demanded specifications and conditions for stretching and warping, this technique is being developed for the immediate objective of manufacturing the radial support for PWRs (one with a stellite padding that supports the cylindrical reactor core baffle from the side at the bottom).



Key:
1. Upper core plate
2. Baffle support
3. Lower core plate
4. Core supporting plate
5. Radial support

Figure 9. An Example for Use in PWR

2. Clamping Devices (applications of crystal controlled alloys and dispersion reinforced alloys)

At present, cold rolled SUS316 and Inconel X-750 are used for manufacturing fastening devices to connect in-pile structural materials (represented by clamp bolts 30 mm in diameter and 150 mm in length), and they have been proving to be fairly satisfactory. However, to further increase the clamping devices' resistance to SCC in high-temperature water, as well as to increase their already high strength, applying single crystal alloys--which are said to be immune to stress corrosion since they lack grain boundaries--and dispersion reinforced alloys--the strength and resistance to corrosion of which are increased by the dispersion of reinforcing grains of oxides, such as alumina and yttrium (Y_2O_3), or the precipitated hardening matter produced during heat treating--to the clamping devices for PWRs are being researched.

(1) Crystal Controlled Alloys

a. Single Crystal Alloy (part 1)

In this research project the objective is to develop a single crystal alloy for use in clamp bolts, using a select Ni-base alloy with high strength and precipitation reinforcing (r" phase) its strength through

the tin bath cooling method. Compared with the multicrystal material currently used, a material with higher values--about 1.5 times in strength at high temperatures and 30 percent higher ductility--has been obtained. Evaluations of such characteristics as resistance to SCC are planned.

b. Single Crystal Alloy (part 2)

In this research project the objective is to develop a precipitation reinforced (r" phase) single crystal for use in clamp bolts, beginning with the widely-used Inconel X-750 and adding Al and Ti in a one-directional coagulating furnace for precipitation. Evaluations are being conducted.

(2) Dispersion Reinforced Alloys (applications of precipitated matter dispersion reinforced alloys and oxide dispersion reinforced alloys)

a. Precipitated Matter Dispersion Reinforced Alloy

In this method an Ni-base alloy is subjected to vacuum dissolution, cold processing and heat treating, with the precipitated matter of the metal compound generated used as the dispersion reinforcing material. Studies are being conducted while examining the product's resistance to SCC.

b. Oxide Dispersion Reinforced Alloy

In this method the currently used Inconel X-750 (base metal) and alumina or yttrium powder that has been subjected to powder molding by the dry-type "Atlighter" method (a method for producing mechanical alloy powder by grinding, using balls) or the melt mix method (a method for forming compound metal powder through jetting molten metal bath and oxide powder by gas atomizing) are dispersed uniformly and extruded for fabrication.

In this technology several factors, such as the size ofthe particles and their uniform dispersion, as well as the wettability, affect the product's strength, so evaluations of such things as resistance to SCC testing are planned.

4.7 Pressure Vessel (stud bolts)

High tensile strength steel is currently used for making stud bolts to fasten the reactor vessel cover onto the reactor vessel proper. During fuel exchange, in BWRs these bolts are left behind to submerge under the water, promoting corrosion (rusting), whereas in PWRs these bolts are pulled out to prevent corrosion, which reduce worker exposure to radiation. Applying a high corrosion-resistant surface treatment to the bolts would probably give them long-term corrosion-resistant capabilities and would eliminate the need to extract them. In this project, among the methods of surface treatment being investigated as applicable to both BWRs and PWRs are 1) multilayer electroplating, 2) turning the surface layer into a kind of stainless by laser alloying, and 3) physical deposition of ion plating using metals such as Ni or Cr.

4.8 Turbine

1. Low Pressure Turbine Blade (Figure 10)

The blade height of the final-stage long blade for the low-pressure turbine directly affects the otuput and performance of a plant, so efforts have long been made to manufacture a larger blade. A blade 52 inches in height has already been developed using existing materials (12Cr steel, 17Cr-4Ni steel). It is possible to build a larger blade using the same materials. However, if a plant is to become more efficient and achieve reductions in size in the future, while retaining the reliability it now enjoys, a light and strong material, that is, a new material high in specific strength, will have to be developed.

To meet this demand, a titanium alloy with a high specific strength and continuous fiber reinforced metals (FRM) has been developed as the material for making the final-stage moving blade for low-pressure turbines.

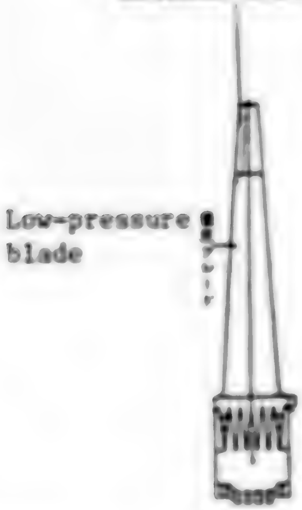


Figure 10. Low Pressure Turbine Blade

(1) Titanium (Ti) Alloy Blade

In order to raise the efficiency of thermal power plants, studies have been made in the private sector of Ti-6-Al-4-V alloy application. If nuclear power plants are to gain increased efficiency and reduce their size in the future, it is necessary to develop a Ti alloy with a higher specific strength and greater forging properties at constant temperature than the Ti-6Al-4V alloy and its forming technology. This research has developed Ti alloys with specific strengths 20 to 25 percent higher than that of the Ti-6Al-4V alloy. Two kinds of Ti alloys are being tested for ductility and ease of forging to evaluate their properties when used as the constant temperature forging material or the basic material as well as to evaluate their constant-temperature forging properties.

Since Ti alloys are active metals, they, unlike ordinary steel or Al, cannot, as a rule, be cast in air, but need to be cast in a vacuum. In the following forging procedure, Ti-6Al-4V (alpha + beta alloy) (an alloy that has a beta safety element, such as vanadium, inserted in its hexagonal columns of an alpha phase) can be cast in air, but the Ti alloy, which is the developmental target in this project, is a near-beta alloy (an alloy that retains its high strength even after reverting to normal temperature while being kept in a beta haploid phase of a cubic shape), which must be cast in an environment of constant temperature during fabrication into a blade of more than 40 inches in length. According to the current plans, smaller blades will be built to be used in testing.

(2) Long-Fiber FRM Blade

The objective of this research is to develop a technique to mold the SiC fiber reinforcing material into the Ti alloy base metal by HIP. The product is expected to have a high relative strength (200 kgf/mm^2 at room temperature) and a high heat-resisting capability, making it possible to produce lightweight and high-strength turbine blades.

Basic studies have already been conducted. Due to the high cost of developing a blade close in size to that of commercial blades, this research has been terminated for now, but will be resumed in the future.

This developmental project has many problems to be solved, such as the wettability between the fiber and base metal and the anisotropy of the two materials, as well as difficulty in fabrication.

2. Erosion Shield for Low-Pressure Turbine Blade

The final-stage moving blade for the low-pressure turbine is used in an environment of damp steam, making it vulnerable to erosion by water droplets. To prevent this erosion, the moving blade has an erosion shield made of stellite, with cobalt (Co) installed as its constituent element at its tip.

From the perspective of reducing worker exposure to radiation, in this research efforts are being made to develop substitutes for stellite-based erosion shielding materials, including surface hardening materials or ceramic coatings of Ni- or Fe-base alloys applicable for 12Cr-based blades in existing turbines, and Ti alloy-based erosion shielding materials applicable for blades made of Ti alloys.

(1) Surface Hardening Materials for Installed Turbines (12Cr, 17Cr steel) (applications of Ni- or Fe-base alloys)

a. As for a Ni-base alloy, with an eye to hardness, a material hardened by several hardening phases has been developed. As for the Fe-base alloy, an Fe-base alloy of the (Mn) system with a high work hardening capacity has been developed. The Fe-base alloy of the high manganese system showed

cavitation erosion characteristics on a par or higher than that of stellite. It was also equal or superior to stellite in terms of hot working, hardness and tensile strength characteristics. After making further improvements, the alloy will be tested.

b. Ceramics/Metal Composite Coating

In this research, efforts are being made to develop an ingot material of the nickel-aluminum-titanium ($Ni_3(Al, Ti)$)/Ti composite material.

(2) Surface Hardening Material for Ti Alloy (applications of near-beta-type alloy)

Using β-type Ti alloy that has been improved over the existing Ti alloy material in terms of resistance to erosion and ease of fabrication into blades, a high hardness Ti-base alloy with as high an anti-erosion capability as stellite has been extracted. The product will undergo tests for resistance to erosion under conditions closer to those found in actual use.

4.9 Cleaning Systems (water treatment)

(1) Cleaning System of Reactor Coolant (applications of ion exchanger)

In the reactor coolant cleaning system used currently, the reactor water is cooled to a lower temperature before treatment because the ion exchange resin cannot withstand the high temperatures of the reactor water. In order to enable the direct cleaning of high-temperature reactor water, the development of an inorganic ion filter for high-temperature water cleaning, a metallic capillary filter impregnated with a metal ceramic (Fi-Ni-O) material with ion absorbing abilities, will be promoted.

(2) Condensate Cleaning System (applications of ion-exchange capabilities of hollow fiber membranes)

In order to clean water in BWR plants, filtration and desalination systems are installed in a series in the condensate and waste processing systems. Technology that would enable the filtration and desalination processes to be carried out in a single system would contribute to greatly reducing plant equipment and plant operation costs.

In this research, in order to upgrade the water treatment equipment, a multifunctional hollow fiber membrane filter has been developed that, in addition to the hollow fiber membrane's excellent filtering capabilities, has had ion-exchange capabilities added.

(3) Radioactive Waste Processing Condensed Liquid Equipment (applications of highly functional separation films)

Conventionally, the condensation of radioactive waste liquids has generally been conducted by the heating and evaporation method, but the high concentrations of chloride in these liquids have tended to cause corrosion

of the metallic materials. To overcome the problem, countermeasures, such as the use of high-class materials (Ti, Inconel 625) or distillation under reduced pressure, have been taken. To solve these problems, the development of a teflon-based hydrophobic film (vaporization and filtration film) has been undertaken that will make it possible to reduce waste liquids from nuclear power plants to about 30 percent of the volume. Bright prospects have been obtained for reducing sodium sulfate (Na_2SO_4), the major component of condensed waste liquids, to 30 percent of the original volume. The product will undergo tests for durability.

4.10 Tanks

(1) Condensed Waste Liquid Tank in Radioactive Waste Processing System (RW condensed waste liquid tank)

Currently a vinyl ester resin lining is used to protect the RW condensed liquid tank in a BWR plant from corrosion. However, the development of a lining material that will have a smaller degree of bulging or spalling of the lining and, therefore, will last longer than the conventional material, is awaited. Efforts to develop such a material are under way based on highly economical fluorine materials or FRP materials with a lifetime of more than 10 years.

Studies will be made of the effect of the formation of fluorine ions and of the workability of the materials.

(2) Auxiliary Cooling System Tanks

Epoxy resin paints, along with thick-film-type primers rich in zinc, are currently used to protect auxiliary cooling system tanks in a BWR plant from corrosion. As with the aforementioned RW condensed liquid tank, a paint with greater longevity is awaited. Therefore, developmental efforts have been undertaken based on the highly economical epoxy resin materials that can withstand use of more than 10 years.

4.11 Incinerator

Refractories (BWR: alumina-zircon bricks, high alumina bricks, mullite silicon carbide bricks; PWR: hard clay bricks) are used in the inner walls of an incinerator in a nuclear power plant.

These inner wall materials are vulnerable to cracks caused by corrosion or thinning due to molten ash, chemical reactions with the ash as a result of incineration, and a repetition of heat cycles for a long period of time, so it is expected that their lifetime can be extended through increasing their capacities to resist corrosion, heat and shock, and abrasion.

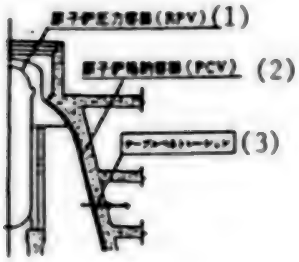
Therefore, techniques to coat refractory surfaces with molten ceramics by sputtering--in this case Al_2O_3 and ZrO_2 have been selected due to the oxidation atmosphere inside the reactor--have been developed.

4.12 Electric Penetration for Containment Vessel (Figure 11)

Epoxy resin is currently used as the insulating and shielding material for electric penetration into the containment vessel, and improvements in the material's properties, such as increased reliability, freedom from deterioration, and greater longevity, are expected.

In this research two kinds of insulators have been developed, one based on Al_2O_3 and the other on soda barium glass.

The development of technology to bond ceramics with metal conductors, as well as heat resistance, durability, and radiation resistance, etc., is being promoted.



Key:
1. Reactor pressure vessel
2. Reactor containment vessel
3. Cable penetration

Figure 11. Electric Penetration for Containment Vessel

4.13 Electrical Instruments

(1) Non-Halogen Flame Retardant Cable

The demand for non-halogen flame retardant cable is high in industrial fields other than the nuclear power industry, so development in this field is fairly advanced. In this research, in an attempt to come up with a flame retardant material for cable sheathing, flame retardant materials such as aluminum hydroxide and polyolefine to which radiation protection agents, such as aromatic compounds, have been added have been selected as the basic materials. Efforts are being made to develop a cost-competitive non-halogen flame retardant cable containing no chloride by kneading and fabricating these materials into a cable.

In the future, tests are planned to evaluate the longevity of the products.

(2) Environment-Resistant Semiconductor Elements

This research is aimed at laying the groundwork for the development of environment-resistant silicon semiconductor elements that may be applicable to the safety and protection systems in nuclear power plants. Various element and device-mounting technologies have been established so far, and bright prospects have been obtained for manufacturing, on a trial basis, a 4K gate array LSI that will be able to withstand an environment of 10^5 rad, 100°C and 100 percent RH.

The product will be tested to evaluate its overall performance, involving such abilities as radiation resistance, heat resistance and moisture resistance.

(3) Neutron Measuring Instrument (LPRM)

Alumina is used in the watertight seals for sensors that detect local output neutrons in the reactor core of a BWR plant, and the development of a seal with increased reliability and longer life is awaited.

To that end, the development of technology that will make it possible to use various kinds of ceramics as alternatives or will improve the material is planned.

5. Conclusion

In consideration of the probability that even a minor problem in a nuclear power plant in Japan would have great social repercussions at home and abroad, the people engaged in the operation and maintenance of light water reactors in Japan have been constantly alert.

In light of this situation, it is not an exaggeration to say that the light water reactor equipment and components are expected to offer increased reliability.

With regard to the maintenance and control of the equipment and components in light water reactor plants, the situation demands that we not be satisfied with the current preventive maintenance, but build on the accumulation of knowledge and implement pioneering preventive maintenance in the form of equipment and components with greatly increased reliability.

The R&D projects involving applications of advanced materials in light water reactors are being asked to meet these requirements, and the technologies will have to be completely satisfactory and be backed by actual experience in a functioning reactor.

In the government's R&D involving applications of advanced materials in light water reactors, the materials targeted for development run the gamut from ones for which there exists little experience to ones which have the potential for commercialization. Of these, those found promising will find application not only in the light water reactors, but also in the thermal power generation and other common industries.

The knowledge and findings obtained in this research will prove beneficial to industry, and the research on advanced materials being promoted by the nuclear power industry is expected to contribute to the invigoration of the entire industry and to the promotion of international cooperation.

Table 2. ANERI's R&D Objectives

B: BWR
P: PWR

No	System	Device	Components	Current Materials	Reactor Type	Advanced Materials
1.	Pumps	Seawater pump	Main axis, casing, impeller	Stainless cast steel SCS14, SUS316	B/P	Modified stainless steel, two-phase stainless steel
			Underwater bearing	Phenol resin, Nitrile rubber	B/P	Al_2O_3 ceramic or Si_3N_4 ceramic
		Reactor coolant system pump	Mechanical seals	Sintered carbon (fixed), Superhard alloy (rotary)	B	C/C composite, short fiber FRM
				Alumina (fixed)/ (rotary)	P	SiC ceramic, Si_3N_4 ceramic
		RW system pump	Casing, impeller	Stainless cast steel	B/P	Ceramics, coating
		Pumps, general	Packing, gasket, O-ring	EP rubber, graphite, asbestos	B/P	C/C composite, FRTP, modified rubber
2.	Valves	Valves, general	Seat	Stellite No 6	B/P	Fe-/Ni-base surface hardening materials, ceramic coating
		Rubber diaphragm valve	Diaphragm seat	Rubber (fiber reinforced)	P	Modified rubber (EPDM) (aramid fiber)
		Valves, general	Ground packing	Rubber, graphite, asbestos	P	C/C composites

3. Piping	Seawater piping	Pipes, joints	Carbon steel (+ lining)	B/P	Composite steel pipes, FRP/FW
	RW system piping	Pipes, joints	SUS316L	B/P	Ceramic coating
4. Heat-transfer equipment	Heat exchanger, heater, etc. (steam generator)	Heat-transfer pipes (Co, Ni elution prevention)	Inconel 600	P	Ceramic coating
		Heat-transfer pipes (resistance to chloride, long life)	SUS316L, 304(L), titanium	B/P	Ceramic coating
5. Control rods drive system	CRD	Guide roller (improved CRD)	Stellite No 3, low-Co-Ni-base alloy	B	Al_2O_3, Si_3N_4, SiC, ZrO_2
		Seals (installed CRD)	Sintered carbon	B	Al_2O_3, ZrO_2 ceramics
	CRDM	Coil assembly	H-type silicon- and sand-filled material	P	Superengineering plastics
6. In-pile machinery	In-pile structures	In-pile structural materials, radial support	Austenite SUS ($Co \leq 0.2-0.05\%$)	B	Low cobalt (super) stainless steel
				P	Surface treatment for Co elution control, ceramic coating
	Clamping devices	Bolts	Inconel X-75C	P	Crystal controlled alloys, dispersion reinforced alloys

7.	Pressure vessel	Stud bolts	Stud bolts	High tensile-strength steel	B/P	Surface treated steel
8.	Turbine	Low-pressure turbine	Blade	12Cr steel, 17Cr steel, titanium alloy	B	Improved titanium alloy
					P	Long fiber FRM
			Blade erosion shield	Stellite No 6, titanium alloy	B	Fe-base or Ni-base surface hardening materials ceramic coating
					P	Ti alloy (near β-alloy) ceramic coating
9.	Cleaning systems (water treatment)	Reactor coolant cleaning system	Ion exchanger	Ion exchange resin: organic materials (stylene)	B/P	Inorganic ion exchanger
		Condensate cleaning system Waste processing and filtration equipment	Ion excnanger, evaporator	Ion exchange resin: organic material (stylene)	B/P	Functional polymer separation films (improved hollow fiber films)
10.	Tanks	RW condensed waste liquid tank	Corrosion-proof lining	Carbon steel, lining	B/P	Paint, resin lining
		Auxiliary coolant system tank	Corrosion-proof painting	Carbon steel, epoxy coating	B	Paint, resin lining
11.	Incinerator	Incineration equipment	Furnace wall material	Refractories (alumina)	B	Ceramic coating

12.	Containment vessel	Penetration	Insulating material for electric penetration	Epoxy	B	Glass, ceramic
13.	Electric devices	Cable	Cable	Rubber, vinyl chloride bridged polyethylene	B	Polyolefine, metallic hydrates
		Electronic components	Semiconductor	Silicon	B	Silicon, etc.
		Neutron measuring instrument	LPRM seal	Alumina	B	Ceramics

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[Article by Isao Nihei, Power Reactor and Nuclear Fuel Development Corporation: "Applications of Advanced Materials in Fast Breeder Reactors"]

[Text] 1. Foreword

Of the advanced materials targeted for applications in fast breeder reactors (FBRs), in this report the structural materials that the Power Reactor and Nuclear Fuel Development Corporation (PNC) plans to research and develop are described, and the directions and tasks of the developmental activity are introduced.

Major requirements demanded of the structural materials for FBRs are that they possess excellent high-temperature characteristics, such as creep, fatigue, and creep fatigue, at high temperatures (in the region of about 500°C) and that they be less adversely affected by such environmental effects as high-temperature liquid metallic sodium and high-speed neutrons in terms of corrosion, mass migration and material strength. High-temperature sodium, in particular, has a high heat conductivity and, therefore, the thermal stress acting on the structural material during temperature changes in a plant is believed to be larger than that of a light water reactor or a thermal boiler. Of these, creep fatigue is a breakage mode that should be addressed at the design level. Shown in Figure 1 are cases of transitory thermal stresses being generated as a result of changes in the sodium temperature. Sodium has a melting point of about 98°C and a boiling point of about 883°C. Due to its wide liquid temperature range, although the temperature range in which FBRs operate internal pressure load working on the structural material is small, from the perspective of earthquake-proof requirements the structural material should be provided with excellent tensile strength. Table 1 shows physical characteristics, and Table 2 chemical properties, of sodium.

Structural materials for Japan's high-speed experimental reactor "Joyo" and prototype reactor "Monju" were selected from existing materials that had proven themselves in such uses as thermal power plants, boilers or chemical plants, and also satisfied the above conditions. They also had to pass rigorous material testing under actual conditions. The major materials include the three kinds of austenitic stainless steel, SUS304, 316 and 321, and two kinds of low alloy ferrite 1/4Cr-1Mo steel (NT materials). In portions where abrasion- and friction-resistance characteristics (tribology behavior) are demanded in sodium, cobalt- or nickel-base alloys are used as the surface hardening materials. In achieving the commercial operation of FBRs, the demands for reductions in construction cost and for plants involving higher operability have been heard increasingly in recent years. Applications of advanced materials as structural materials are expected to meet these requirements, and research and development is being advanced. Depending on the reactor, the development of advanced materials for FBRs can be divided into the following two

stages: the first stage is the development of advanced materials for the demonstration reactor planned for construction in the 1990s; the research and design work is already being advanced, and within a few years the materials will be selected and their specifications determined. To that end, one approach would be to apply highly functional materials by improving the materials used in the "Joyo" and "Monju" and by developing advanced materials out of the existing materials. These materials could be termed advanced materials for the FBR. The design specifications for the commercial reactor targeted for development by the year 2030 or so would be more demanding, and could be met by producing and applying innovative new materials. This report introduces PNC's R&D projects in these two stages of materials development.

2. Circumstances and Backgrounds

The New Long-Term Program for Atomic Energy unveiled by the Atomic Energy Commission in 1987 called not only for the development of technical innovations in the nuclear energy field, but also for the promotion of the atomic energy frontier research that will have ripple effects on science and technology as a whole. It positions materials technology as the fundamental technology for achieving breakthroughs in the wall of existing technologies and for establishing creative technologies. Behind this proposition is the recognition that, as nuclear energy technology has become increasingly sophisticated, the conventionally obscure materials have, in fact, played an important role and are the deciding factor in determining the design and operation of a plant and in solving problems. In the wake of this proposition, the Science and Technology Agency has started a survey of the state of materials research as undertaken by the nuclear energy-related corporations, national research institutes, universities and major domestic organizations.

The criteria for developing structural materials at PNC have included the R&D of elemental technologies that will be attainable with the existing technology. Concrete research items include the gathering of data involving materials properties necessary for designing the FBR, testing to establish a method to evaluate materials strength for the design of high-temperature structures, making compatibility evaluations on each of the materials in the FBR environment (sodium, fast neutrons, high-temperature steam) and conducting R&D on how to reflect these evaluations in the design, manufacturing and materials strength standards. With the imminent commercialization of the FBR, PNC's basic policy has been established along the following line: based on the strength of the conventional project-type materials development technology (needs oriented), it is to further strengthen the foundation for materials technology by undertaking materials development, referred to as the seed searching type or seed fostering type, to qualitatively transform the research environment so that creative technologies can be developed, and to have the results of such efforts reflected in the commercial FBR.

The materials technology research at PNC will be promoted along the following pillars of 1) development of materials seeds, 2) reinforcing the

abilities to exploit materials needs, and 3) sophistication in the evaluation technology of materials, which will be followed by an effort to establish an easy-to-use database system.

From this concept, PNC will promote research involving methods to apply advanced materials and what R&D tasks exist if this is to become feasible, while taking into consideration the materials needs for the entire nuclear energy technology field, including FBR, ATR and the nuclear fuel cycle, as well as the situation surrounding PNC and the materials seeds in other industrial fields.

3. Applications of Advanced Materials in Demonstration Reactor

The structural materials for the demonstration reactor to be developed following the "Joyo" and "Monju" will basically be selected from among those materials that have already proven themselves in various uses, but studies are being conducted involving applications of advanced materials from the perspectives of rational design and reductions in construction costs. Among the candidates for application are 1) high chromium molybdenum steel for the steam generator and the secondary system, 2) stainless steel with improved ductility, 3) stainless steel capable of withstanding neutrons, and 4) low cobalt surface hardening materials. These materials are already being used in other fields and R&D work has already been started on some of them for use in modifying the FBR structural materials.

3.1 High Chromium Molybdenum Steel

Due to such features as high temperature strength comparable to that of stainless steel, small thermal expansion and high heat conductivity, high chromium molybdenum steel has small thermal stress, and this feature is especially beneficial in modernizing piping. The steel is also effective against stress-corrosion cracking (SCC) on the water side, and its application as the material for use in secondary system piping and steam generators is being studied. This application is expected to bring about such benefits as the rationalization of design, improved reliability and reductions in construction costs. Listed in Table 3 are some of the major types of high chromium molybdenum steel, the research and development of which is under way. After conducting strength tests in air to obtain data on their basic materials characteristics and other environmental impact tests, the results are scheduled to be reflected in the material strength standards and the design policy for high-temperature structures.

3.2 Improved Stainless Steel with High Ductility

Attempts to improve the existing SUS 304 and 316 in such areas as ductility, especially creep rupture ductility, and high temperature strength by adding trace amounts of additional elements have been made, and good results have been obtained with low carbon and nitrogen additives. Excellent materials have been reported, especially among those with SUS316LCN as the base material, and reduced creep fatigue damage, and hence the development of FBR plants capable of operating at higher temperatures, is expected.

3.3 Neutron-Resistant Stainless Steel

Stainless steel loses its creep strength when bombarded with thermal neutrons. The major cause for the lowering of creep strength is believed to be the formation and coagulation of helium atoms inside the steel resulting from irradiation, and research and development is under way to study the effect of the concentration of boron inside the steel. Among the effects are reductions in the amount of structural materials for the core support and of the neutron-shielding materials for the reactor vessel materials. Rationalization of the neutron environmental impact evaluation standards can also be expected.

3.4 Low Cobalt Surface Hardening Materials

Coatings of surface hardening materials have been applied on portions where tribology behavior, such as friction or abrasion, occurs in sodium. Stellite has been widely used due to its excellent features such as good workability and high resistance to the sodium environment. However, it contains about 50 percent cobalt, and the cobalt is discharged into the sodium system by elution or as friction powder over time. The discharged cobalt is transformed into radioactive Co-60 as a result of neutron bombardment, which adheres to the walls of the equipment. This has been believed to be a cause for operator exposure to radiation during routine inspections or repairs. The efforts to develop materials low in cobalt content have been actively advanced, and several nickel-base alloys are being commercialized. Listed in Table 4 are surface hardening materials low in cobalt content.

4. Development of Advanced Materials Toward Practical-Use Reactor

When the goal is the commercialization of the FBR in 2030, advanced materials will be more widely applied in the reactor than in the demonstration reactor, and it may be possible to have great breakthroughs in the existing technologies. To that end, it is important to start a systematic survey and research activity now and establish long-term perspectives for research and development. Consequently, PNC has decided to conduct a survey of where the needs for FBR structural materials exist and one of where the seeds for advanced materials exist, as well as to conduct research involving where problems will be encountered when correlating needs with seeds.

4.1 Needs for FBR Structural Materials

The needs for FBR structural materials vary widely, and also need to be studied from the perspectives of the timing of development and the ease or difficulty of development. Therefore, the needs are classified into the following categories for reasons of simplicity:

(1) Creation of innovative new materials

(2) Innovative improvements of existing materials by adding new capabilities

(3) Improving the performance of existing materials, upgrading them, and expanding their scopes of use

(4) Improving and upgrading the database, and analysis and evaluation technology

(5) Achieving innovative improvements and upgrading of equipment and machinery through development of new technologies.

A. Creation of Innovative Materials

Meeting the needs for innovative materials requires the development of extremely high levels of frontier technology, and the following materials have been proposed as candidates for development: 1) materials for use in uniform welds and welding materials requiring no heat treating, 2) sodium- and radiation-resistant materials, 3) materials that are characterized by high resistance to thermal stress and high heat conductivity, as well as by low thermal expansion, 4) materials characterized by resistance to high-temperature alkaline corrosion, and 5) materials that will realize "visible sodium." Included in the needs common to all are 6) development of materials that scarcely succumb to the creep effect and 7) development of self-repairing materials. Among the surface treatment materials for the structural materials are 8) coating materials for crack detection and inhibition as well as thermal stress mitigation.

B. Innovative Improvements of Existing Materials by Adding New Capabilities

These needs can be basically met through existing materials, but the technologies involved are highly pioneering. Among the materials targeted for development are 1) materials with high attenuation for use in earthquake-proof structures and 2) materials impervious to tritium.

C. Improving the Performance of Existing Materials, Upgrading Them and Expanding Their Scope of Use

The targets for development of materials contained in this category are clear-cut, and concrete needs for their development exist. They include 1) materials capable of withstanding ultrahigh temperatures; 2) insulating materials for coping with abnormal events in the reactor; 3) welding materials capable of withstanding thermal stresses to reduce costs; 4) applications of ferrite steel in the primary system by taking advantage of the metal's resistance to neutron swelling; and development of 5) lightweight and high-strength materials and 6) spring materials for system upgrading. In the field of surface treatment materials there are 7) materials with high resistance to erosion and abrasion, and 8) materials with resistance to sodium wettability. Strong needs also exist for 9) high-performance insulating materials.

D. Improving the Database, Its Analysis and Evaluation Technology

The items contained in this category play an important role in studying the direction for developing advanced materials and in establishing standards for their evaluation. They are also expected to exert a great ripple effect on other fields, such as structures and systems. The major needs include 1) the establishment of a method to evaluate the strength of structural materials in the FBR operative temperature domain, 2) applying rupture dynamics to establish ISI and LBB theories, and 3) introducing an inelastic analysis method for design rationalization. Another need involves the establishment of 4) databases for structural materials in order to make these evaluation methods practical. The need for developing a diagnostic technique for the surplus life of structural materials has also been proposed in order to extend the FBR lifetime.

E. Achieving Innovative Improvements and Upgrading in Equipment and Machinery Through Development of New Technologies

These needs are mostly associated with functional capabilities. Included in this category are development of 1) laminated or duplex piping materials as countermeasures against leakage, 2) insulating duct materials for superconductive electromagnetic pumps, and 3) vibration-absorbing materials as countermeasures against earthquakes and to diagnose abnormalities in equipment operation. As a specific capability there is the development of 4) adhesives for bonding structural materials. The field of instruments to test structural materials includes the development of 5) a device to measure minor changes in the internal heat energy, 6) a high-precision nondestructive testing device for extremely thick steels, and 7) a local-strain gauge.

4.2 Trends of R&D of Advanced Materials (Seeds)

Advances in the research and development of advanced materials are eagerly awaited not only because these materials are seeds for the leading-edge science and technology, but also because they are indispensable for achieving such national goals as the development of nuclear energy and space. Therefore, developmental efforts have been actively advanced at national research institutes, universities and materials manufacturers. By gathering data involving the trends of R&D of material seeds from as many of these organizations engaged in advanced materials research as possible and, in addition, by surveying the developed materials, PNC has decided to incorporate the findings into a database, which will be used as a guide for drafting plans for the future development of advanced materials as structural materials for FBRs.

The first direction of research and development is the developmental activity aimed at creating new capabilities, and upgrading and multi-functioning existing capabilities in the existing materials fields (metals, ceramics and polymers) and in intervening fields. By pursuing the causal relationships among the composition and structure and the features and capabilities of materials at the atomic and particle levels,

among others, the R&D activities are aimed at creating new capabilities from existing materials or to upgrade the existing capabilities of existing materials or impart them with multifunctional capabilities. Targeted for R&D are amorphous alloys, shape memory alloys, upgraded functioning of magnetic materials, heat- and corrosion-resistant ceramics, and FRM. Rapid advances have occurred recently in thelayered thin-film technology and surface treatment technology, and materials with a tilting capability or the capacity for thin-film stacking have been developed. Furthermore, extending the concept of shape memory alloys a step further, the creation of materials which, provided with a time axis, have self-repair or self-diagnosis capabilities is being studied.

The second direction of research and developmentis away from the framework of conventional materials, and includes the goals of creating advanced materials, such as ultra-pure ceramics and FRM, under ultrahigh temperature, ultrahigh pressure or no gravity conditions.

Shown in Table 5 are advanced materials that may be used as FBR structural materials.

4.3 Establishing Correspondence Between Seeds and Needs

After sorting out the tasks for research and development if the above needs for materials are to be met, then picking up material seeds believed to be able to meet the material needs, followed by evaluating such factors as what effects the development of the material seeds will have, if the accumulation of necessary technology exists, how long the development will take, and what ripple effects the development will have, the following R&D tasks have been singled out as deserving immediate research and development.

(1) Responses to Creation of Innovative Materials

If composite materials are to be used as thermal-stress resistant structural materials for FBRs, FRMs characterized by high resistance to radiation irradiation and sodium need to be developed. The composites will have to satisfy such requirements as high resistance to heat, good affinity between the base material and fiber, and little or no breakage arising from the interface, etc. In developing materials capable of withstanding ultrahigh temperatures for use as safety and protective wall materials, it will be necessary to develop ceramics capable of withstanding temperatures of 2000°C or higher and ultrahigh temperature-resistant metals, as well as the technologies for laminating or joining such materials. In developing shape memory alloys for use as joints for pipes and actuators for the control rod drive mechanisms, alloys offering a high deformation temperature and an ample reverting force, yet characterized by good sealing capabilities and fatigue characteristics, will have to be created.

(2) Responses to Innovative Improvements of Existing Materials by Providing Them with New Capabilities

Some structural support materials with high attenuation capabilities have been on the market for use as shake-proof materials, and their potentials for commercialization are high. Structural materials with a surface treatment making them impervious to tritium have problems with the reliability of the coating when fabricated into large structural materials and, therefore, the technology to ensure the coating soundness must be developed.

(3) Responses to Improvements in Performance of Existing Materials, Their Upgrading and Expanding Their Scope of Specifications

If it becomes possible to elevate the performance of existing materials, such as ceramics, carbon fiber composite materials, and polymers, by arming them with resistance to high temperatures or special capabilities, it will become possible to meet a large number of the needs. Studies are currently being conducted on high chromium molybdenum steel to determine if it can be used in the demonstration reactor's secondary system, but the metal's application may be expanded to include the primary system. For this to become feasible, the effect of the steel on neutron irradiation will have to be evaluated, and upgraded specifications and standards for the metal will have to be introduced. In developing low radioactive materials, it will be necessary to explore the candidate materials among the non-cobalt and nonferrous systems and to solve problems associated with them, such as how to secure their strength at high temperatures, and their resistance to thermal stress and sodium. The same can be said of lightweight, high-strength materials.

(4) Responses by the Improving and Upgrading Database, Analysis and Evaluation Technology

The items in this category address the reliability, and development and upgrading of the soundness evaluation method, and by nature they are extensions of current projects. Among the tasks for development are 1) upgrading the method of evaluating weld strength, 2) upgrading the method of evaluating creep fatigue, 3) application of the non-linear destruction dynamics method, 4) development of a uniform-type component equation for inelastic design, and 5) construction of a database for structural materials. In developing the technology to diagnose the surplus life of FBRs, the results will be far-ranging, including the development of monitoring technology and technology to analyze stress-strains, and the introduction of the high-temperature destruction dynamics method.

(5) Responses to Demands for Innovative Improvements and Upgrading Machinery and Equipment Through Development of New Technologies

The current seeds are capable of meeting the needs for the development of structural materials for layered pipes and duplex pipes, which are required for the technology to eliminate the secondary coolant system

in FRBs, and the current tasks involve R&D of the operation of the sodium system and its construction. As the material forducts in the superconductive electromagnetic pump, FRMs and ceramics are under consideration, and the tasks involve how to provide them with high-temperature strength and resistance to thermal stress and sodium. In order to develop high-precision nondestructive testing equipment, it is necessary to develop light-emitting or sound-emitting devices of X-rays, gamma rays and supersonic waves.

The above priority research tasks are listed in Table 6.

5. Conclusion

The FBR development in Japan has been supported by research and development work in many fields. Since the operation of the "Joyo" began in 1977, the reactor has been running at a high operating rate for approximately 10 years and, in the process, has been contributing to the accumulation of precious experience. These achievements are reflected in the development of the "Monju" that is scheduled to reach criticality in 1992, and also in the development program of the demonstration reactor. These programs are judged to be progressing steadily. The priority R&D tasks listed above have been selected after taking into consideration the needs for advanced materials that have become apparent during the design, building and operating of the above reactors, as well as over the long course of history of reactor research and development, and some of them will be undertaken in 1988. Our experience with the FBR, however, is short and shallow when compared with our accumulation of knowledge about light water reactors and, in the field involving the application of advanced materials, much will have to await the results of future research and development. It is deemed necessary that, under the leadership of project promoters, increased cooperative relationships be maintained among the national research institutes, universities, related research organizations and equipment manufacturers.

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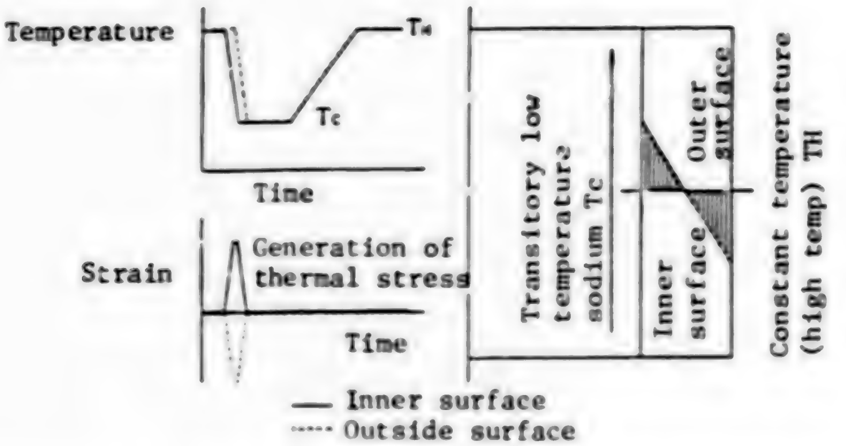

Figure 1. Generation of Transitory Thermal Stress with Changes in Sodium Temperature

Table 1. Physical Properties of Sodium

1.	Atomic weight	22.995
2.	Melting point [°C]	97.8
3.	Heat of fusion [cal/g]	27.05
4.	Increase in volume accompanying fusion [%]	2.5
5.	Boiling point [°C] (760 mm Hg)	883
6.	Heat of vaporization [cal/g]	1,005
7.	Steam pressure [mm Hg] (°C)	1(440), 10(548), 100(696), 200(752), 400(815)
8.	Density [g/cm^3(°C)]	0.928(100), 0.891(250), 0.854(400), 0.817(550), 0.780(700)
9.	Specific heat [cal/g/°C(°C)]	0.3305(100), 0.3200(200), 0.3055(400), 0.2998(600), 0.3030(800)
10.	Coefficient of viscosity [cP(°C)]	0.686(103.7), 0.504(167.6), 0.381(250), 0.269(400), 0.182(700)
11.	Electrical resistance [μΩ(°C)]	9.65(100), 13.18(200), 14.90(250), 16.70(300), 18.44(350)
12.	Surface tension [dyn/cm/°C(°C)]	206.4(100), 199.5(250)
13.	Heat conductivity [cal/s/cm/°C(°C)]	0.2055(100), 0.1947(200), 0.1809(300), 0.1701(400), 0.1596(500)

Table 2. Chemical Properties of Sodium

	$\Delta H_{200}°$ [kcal]	$\Delta F_{290}°$ [kcal]	$\Delta H_{400}°$ [kcal]	$\Delta F_{400}°$ [kcal]	$\Delta H_{500}°$ [kcal]	$\Delta F_{500}°$ [kcal]
$2Na(c)+1/2O_2(g)-Na_2O(c)$	-100.7	-91.4				
$2Na(1)+1/2O_2(g)-Na_2O(c)$			-104.20		-104.21	
$2Na(c)+O_2(g)-Na_2O_2(c)$	-120.6					
$Na(c)+H_2O(1)-NaOH(c)+1/2H_2(g)$	-33.67	-35.34				
$Na(1)+H_2O(g)-NaOH(c)+1/2H_2(g)$	-45.7	-37.4	-45.56	-34.40	-44.87	-28.91
$Na(1)+1/2H_2(g)-NaH(c)$	-13.7					
$Na(c)+1/2Cl_2(g)-NaCl(c)$	-98.23	-91.79	-98.85	-90.23	-98.75	-87.97
$Na(c)+Ch_3OH(1)-NaOCH_3$ (in Ch_3OH)$+1/2H_2(g)$	-48.1					
$Na(c)+1/2F_2(g)-NaF(c)$	-136.0	-129.3				
$Na(c)+1/2Br_2(1)-NaBr(c)$	-86.03					
$Na(c)+1/2I_2(c)-NaI(c)$	-68.84					
$2\ Na(c)+S(c)-Na_2S(c)$	-89.2					
$3\ Na(c)+B(c)-Na_3B(c)$	-45.6					
$2\ Na(c)+2C(c)-Na_2C_2(c)$	-4.1					
$Na(c)+Sn(c)-NaSn(c)$	-12					
$Na(c)+Hg(c)-NaHg(c)$	-10.2					
$Na(c)+Pb(c)-NaPb(c)$	-11.6					

Table 3. Metallic Structure and Features of High Chromium Molybdenum Steel

Kind of Steel	Metallic Structure	Features
9Cr-1 Mo steel	Annealing material--Ferrite + coarse carbide	Resistance to high temperature oxidation
	NT material--Temper martensite	High-temperature strength
Mod 9Cr-1 Mo steel	NT material--Temper martensite	High-temperature strength and weldability
Low carbon 9Cr-1 Mo-V Nb steel (Tempaloy F-9)	NT material--Temper martensite + δ ferrite	High-temperature strength and weldability
9Cr-2 Mo steel (HCM-9M)	NT material--Temper martensite + δ ferrite	High-temperature strength and weldability
9Cr-2 Mo-V Nb steel (NSCR 9)	NT material--Temper martensite + δ ferrite	High-temperature strength
12Cr-1 Mo-V steel		
12Cr-1 Mo-V.W steel (HT-9)	NT material--Temper martensite	High-temperature strength
2-1/4Cr-1 Mo steel	Annealing material--Ferrite/pearlite	
	NT material--"Penite"	Increased resistance to decarbonization
2-1/4Cr-1 Mo-Nb·Ti steel (stabilizer)	NT material--"Penite"	Resistance to decarbonization
Alloy 80	Liquid--Austenite	High-temperature strength

Table 4. Chemical Composition of Surface Hardening Materials

Material	Chemical Composition (Wt.%)								
	Cr	B	Si	Fe	C	Mo	W	Ni	Co	
Stellite No 6*	28.0				1.0		4.0		Bal	
"Fukudalloy" 453	10.0	0.5	5.5	5.0	1.0		2.0	Bal		
"Fukudalloy" 455	25.0	0.8	6.5	6.0			2.0	Bal		Sn 0.5
"Colmonoy" No 5	11.5	2.5	3.75	4.25	0.65			Bal		
"Colmonoy" No 6	13.5	3.0	4.25	4.75	0.75			Bal		
"Toriballoy" 700	15.5		3.4		0.06	32.5		Bal		
"Meteko" 14E	14.0	2.75	3.5	4.0	0.6			Bal		
"Meteko" 15E	17.0	3.5	4.0	4.0	1.0			Bal		

* Comparison material (Co-base alloy)

Table 5. Advanced Materials for Structural Materials

Material	Features	Applications
Shape memory alloy	Memory of shape	Joints
Amorphous alloy	High strength, chemical activity, radiation resistance	Primary system and in-pile structures
Superhigh heat resistant alloy	Heat resistance	Core support, core catcher
Intermetallic compound	Resistance to heat and oxidation, lightweight	Structural support, sodium receiver
Vibration-absorbing metal	Resistance to earthquakes	Structural support
Low activation materials	Low induced radiation	In-pile structures
Duplex pipe with foaming metal	Detection of sodium leak	SG heat transfer pipe
Precipitation reinforced alloy	High strength	Flange, tube plate, structural support
High-strength ferrite steel	High strength	Vessel, piping, SC tube plate
High-strength austenite steel	High strength	Vessel, piping
Composite materials	Corrosion resistance, light-weight, high strength	Vessel, piping
Ceramics	High strength, heat insulation	Structural support, liner, heat insulating material
Tilt function materials	Heat insulation, electric insulation, compound functions	Vessel, piping

Table 6. Results of Selection of Priority Research Tasks

1. Creation of innovative materials

   a. Materials resistant to radiation and sodium
   b. Materials resistant to ultrahigh temperatures
   c. Shape memory alloy

2. Innovative improvements of existing materials by providing them with new capabilities

   a. High attenuation materials
   b. Materials impervious to tritium

3. Improving or upgrading the capabilities of conventional materials, and expanding the scope of their applications

   a. High chromium molybdenum steel for use in the primary system
   b. Low activation materials
   c. Lightweight and high-strength materials

4. Improving or upgrading database, its analysis and evaluation technology

   a. Upgrading the method of evaluating the strength of high-temperature materials
   b. Preparing the database for structural materials
   c. Development of surplus life diagnostic technology

5. Innovative improvements or upgrading of machinery and equipment through development of new technologies

   a. Structural materials for layered piping and duplex pipes
   b. Materials for ducts in superconductive pumps
   c. Materials for high-precision nondestructive testing equipment

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